THE INFLUENCE OF REPETITIONS PER SET ON BACK SQUAT AND BENCH PRESS REPETITIONS IN RESERVE RATING ACCURACY

By

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ABSTRACT

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This study examined the effect of repetitions per set as a function of changing load (percentage of one-repetition maximum) on the accuracy of intraset repetitions in reserve (RIR) predictions in the back squat and bench press. Twelve resistance trained men completed three multi-set back squat and bench press training sessions that differed in the number of target repetitions (session 1: 10 repetitions; session 2: 8 repetitions; session 3: 6 repetitions). The last set of each session was performed until muscular failure in which subjects verbally indicated when they perceived 4 RIR and 1 RIR. For each RIR prediction, RIRDIFF [perceived RIR - actual RIR] was calculated.

Differences in RIRDIFF were analyzed using both raw RIRDIFF (including positive and negative values) and absolute RIRDIFF (absolute values) via MANOVA and factorial ANOVA. The model controlled for the covariates session-type, percentage of 1RM, and total repetitions per set. Overall, RIR accuracy at the predicted 1 RIR was significantly greater (i.e., lower absolute RIRDIFF) than at the predicted 4 RIR in both

the bench press (4 RIR: 1.00 ± 0.18 vs. 1 RIR: 0.69 ± 0.12; $p = 0.028$) and the squat (4 RIR: 1.43 ± 0.31 vs. 1 RIR: 0.79 ± 0.26; $p = 0.007$). No covariates significantly affected RIR accuracy ($p = 0.085$ – 0.518) at the predicted 1 RIR. However, at the predicted 4 RIR, the covariate repetitions per set affected raw RIRDIFF in both the squat ($p = 0.007$) and bench press ($p < 0.001$), indicating that subjects tended to overpredict RIR in lower repetition sets and underpredict RIR in higher repetition sets.

These results indicate that trained men can predict RIR close to failure within <1 repetition of error and under various conditions. Further, trained men may overpredict RIR in lower repetition sets and underpredict RIR in higher repetition sets when training further from failure.

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I. INTRODUCTION

Recent literature indicates that performing resistance training sets to momentary failure (i.e., the inability to complete a repetition despite maximum effort) is not required to maximize muscular hypertrophy or maximal strength (1, 2). Further, performing sets to failure elongates temporal recovery compared to non-failure training even when total volume (sets × repetitions × load) is equated (3). Consequently, training to failure may compromise weekly training volume, load lifted, and frequency, each of which play important roles for hypertrophy (4, 5, 6) and strength outcomes (6, 7, 8). For these reasons, it is important to accurately gauge proximity to failure to ensure the appropriate stimulus is achieved and to mitigate fatigue.

Traditionally, resistance training load is prescribed using a percentage of one-repetition maximum (1RM) or repetition maximum (RM) zones (9). Despite the common usage of percentage-based loading [e.g., 4 (sets) × 8 (repetitions) at 70% of 1RM], there is large interindividual variation in the number of repetitions that can be performed at a given percentage of 1RM (10). Recent data found a range of 6-28 repetitions performed among trained men and women during a set to failure at 70% of 1RM in the back squat (11). Further, an RM zone prescription necessitates performing repetitions to failure. Therefore, since both traditional strategies may lead to unintentional failure training and unnecessary fatigue, autoregulation strategies such as the repetitions in reserve (RIR) scale may be useful.

Zourdos et al. (12) developed the RIR scale for individuals to gauge the number of repetitions remaining during or after a resistance training set, facilitating an alternative load prescription strategy. For example, a prescription of 4 × 8 at 2 RIR stipulates a trainee should choose a load they believe will result in the eighth repetition occurring with 2 RIR. However, the ability of RIR-based load prescription to control for proximity to failure and mitigate the limitations of traditional methods depends upon RIR rating accuracy.

A recent meta-analysis from Halperin et al. (13) indicated that RIR is underpredicted, on average, by 0.95 repetitions. Halperin et al. also conducted exploratory meta-regressions and reported that RIR prediction accuracy is moderated by the number of repetitions performed in a set, the number of sets performed, and the proximity to failure in when the RIR prediction was made. However, these moderating factors are all interrelated; thus, it is not currently known which moderator drives prediction accuracy.

For example, Odgers et al. (14) found that trained men who performed four sets of the hexagonal bar deadlift to failure completed 10.07 ± 2.76 repetitions on set one with an RIRDIFF (predicted - actual RIR) of 1.58 ± 1.26 repetitions when predicting 4 RIR. However, Odgers et al. also reported that RIRDIFF improved to 0.54 ± 0.75 when performing ~3.5 fewer repetitions (6.85 ± 2.08) on set four than on set one. Although Odgers et al. showed that RIR accuracy improved from set-to-set and with fewer repetitions in a set, it cannot be ascertained which variable accounted for the improvement since these moderators occurred concomitantly.

Mansfield et al. (15) had trained men predict RIR during the bench press after completing eight repetitions at 60% of 1RM and three repetitions at 80% of 1RM, which resulted in intraset RIR predictions made closer to failure in the 80% condition. Subjects had a greater RIRDIFF (predictions were more inaccurate) at 60% (7.03 ± 0.62) versus 80% (2.20 ± 0.37). Further, Mansfield reported that RIRDIFF was significantly lower on sets two and three versus set one. Overall, these data agree with Halperin et al. (13) that various factors are related to RIR accuracy. However, similar to Odgers et al. (14) it cannot be deduced which factor is most influential in RIR accuracy. Importantly, proximity to failure may have an independent effect on RIR accuracy as Zourdos et al. (16) observed RIRDIFF during a back squat set to failure in trained men at 70% of 1RM was more accurate at 1 RIR (2.05 ± 1.73) than at 3 RIR (3.65 ± 2.46), which was more accurate than 5 RIR (5.15 ± 2.92). Ultimately, to further understand which moderators drive RIR accuracy, research should compare RIR predictions at the same intended proximity to failure between sets with a different target number of repetitions.

Therefore, the primary aim of this study was to examine the accuracy of intraset RIR predictions when verbally indicated at 4 and 1 RIR before continuing the set to failure with target repetition ranges of ~10, ~8, and ~6 repetitions in the squat and bench press. We hypothesized that RIR predictions would be more accurate during lower repetition sets and at the predicted 1 versus 4 RIR.

II. REVIEW OF LITERATURE

Introduction

Resistance training program design traditionally focuses on the training variables volume, load (% of 1RM), and frequency (4-9). Recently, the variable proximity to failure, which can be defined as the number of repetitions in reserve (RIR) that remain at the end of a set, has gained attention (1, 2). Acutely, proximity to failure influences the time course of recovery following resistance training (3, 17), which can indirectly influence strength and hypertrophy via influencing the volume, load, and frequency that can be tolerated. When reviewing the research broadly, the influence of proximity to failure on longitudinal strength and hypertrophy is unclear (18), but individual studies indicate that proximity to failure has the potential to influence these outcomes (19-26).

Percentage of 1RM-based resistance training prescriptions may lead to varying proximities to failure, as evidenced by the wide range of repetition performance of 6-28 (mean: 14 ± 4) in the back squat in trained participants at 70% of 1RM reported by Cooke et al. (11). For example, a generalized prescription of 70% of 1RM × 10 repetitions may lead to failure for some, while others may have more than 10 RIR. Similarly, repetition maximum zones can be used to prescribe resistance training (9) but require training close or to failure (18).

A potential solution for monitoring and manipulating proximity to failure is RIR-based RPE. Positives of this method include that it is free, universally accessible, and inherently accounts for short-term performance fluctuations. Indeed, RIR-based RPE is an effective method for resistance training prescription (27, 28). However, the utility of RIR-based RPE is dependent upon the accuracy of the rating. Since the chief limitation of RIR-based RPE is that it is subjective, it is prone to inaccuracy in certain contexts.

RIR-Based RPE History

Rating of Perceived Exertion was originally applied to cardiovascular exercise using a 6-20 scale (29) and was later adapted to a 1-10 scale (30), which has been employed in resistance training prescriptions. However, since Borg RPE is a measure of general exertion, a chief limitation of this scale is that the anchoring of the rating is not objective (e.g., scores are anchored by subjective descriptors). This may explain why Borg RPE scores during resistance training sets to failure are sometimes submaximal (31, 32, 33). This is opposed to RIR-based RPE which has objective anchors for ratings (i.e., a given RIR score, or at maximum, no more repetitions remaining).

RIR-based RPE has a significant inverse relationship with barbell velocity in both the back squat and bench press (12, 34); in other words, as load increases and velocity declines, RPE increases ($r = 0.85$-0.88 in experienced lifters; $r = 0.77$-0.85 in novice lifters). Further, Hackett et al. (31) reported a significant correlation between estimated and actual RIR in male bodybuilders ($r \geq 0.93$), indicating that lifter reported RIR is a valid measure of resistance training proximity to failure.

RIR-Based RPE can be used as both a prescriptive method and a monitoring tool. For resistance training prescription, load can be autoregulated via RPE zones by allowing the lifter to select a load to land within a target RIR-Based RPE range (e.g., 3 × 8 repetitions at 6-8 RPE) (35). Volume can be autoregulated via the RPE stop method, in which sets with predetermined repetition targets are repeated with a given load until a predetermined RIR-Based RPE is reached, and then no further sets are performed (36). For resistance training monitoring, RIR-Based RPE at a submaximal load can inform daily maximum capabilities (37), which may be beneficial as individualized load progression methods are superior to fixed progression methods (38, 39).

Factors Influencing RIR-Based RPE Accuracy

While there are multiple training prescription and monitoring methods that incorporate RIR-based RPE, the utility of these methods is dependent upon the accuracy of the RPE rating. How inaccurate one must be to render training less effective is not yet clear. However, depending on the prescription method employed, rating inaccuracy can lead to considerable differences in the completed training. For example, if autoregulating load via RPE zones, overrating a set by three RIR would be approximately equivalent to a load more than 10% lower than desired (40). Thus, understanding the factors influencing RIR-based RPE accuracy can better inform the context in which it is best applied.

A chief positive of RIR-based RPE is that its anchoring is objective; that is, subject-reported RIR-based RPE can be compared to how many more repetitions are actually completed before reaching muscular failure (i.e., RPE 10). This difference (actual minus predicted repetitions to muscular failure) can be referred to as the RIR-difference. A recent meta-analysis on RIR rating accuracy reported an average RIR-difference of 0.95 repetitions, indicating that RPE is overestimated on average (13). However, the authors reported considerable heterogeneity in RIR-difference, as evidenced by an I^2 value of 97.89%. This is likely in large part because the 12 studies included in this meta-analysis varied considerably in the context of the resistance training and RPE/RIR reporting methodology. Thus, a detailed examination of the influence of individual factors on RIR-based RPE accuracy through the lens of individual studies is warranted.

1) Training Experience

The meta-analysis by Halperin et al. (13) reported that training status (i.e., number of months of training history) did not meaningfully moderate RIR-based RPE prediction accuracy. However, it is important to note the range of training statuses examined in this meta-analysis: all except for two included studies included subjects with at least a full year of resistance training or required strength standards reflective of training for multiple years (14). However, other studies not meeting these criteria sometimes report different findings. For example, one study examining RIR prediction accuracy categorized 141 participants into an orientation group (<1.5 months experience), a beginner group (1.5-6 months training experience), an experienced group (6-12 months experience), an advanced group (12-36 months experience), or an expert group (>36 months experience) (41). Participants indicated how many repetitions they believed they could perform to momentary failure prior to a set on the seated row, chest press, leg press, biceps curl machine, lat pulldown, and weighted sit-up. The authors reported that accuracy generally improved (i.e., lower RIR-differences) as training experience increased. For instance, the average RIR-difference for the chest press was 4.33, 4.00, 2.58, 1.91, and 1.57 for the orientation, beginner, experienced, advanced, and expert groups, respectively. However, the load used by the more experienced groups was also generally greater than the loads used by the less experienced groups, potentially playing an independent role in RPE rating accuracy. In contrast, Hackett et al. (42) did not find a significant interaction between training status and intra-set RIR rating accuracy on the chest press and leg press. It is important to note that both studies utilized machine-based training, which requires a lower skill component. Overall, the relationship between training experience and RIR-based RPE rating accuracy requires further study but may not be a primary factor influencing RIR-based RPE rating accuracy when load is matched.

2) Exercise Selection

The exercise performed may also independently affect RIR-based RPE prediction accuracy; the meta-analysis by Halperin et al. (13) included a sub-group analysis of upper versus lower body exercise and reported a greater average RIR-difference for lower (1.51 repetitions) compared to upper body exercise (0.92 repetitions). Once again, this difference may be imprecise due to study design and methodology heterogeneity, as evidenced by a wide 95% confidence interval for the upper minus lower body RIR-difference (-2.30-1.13 repetitions). Findings from Hackett et al. (42) align with these meta-analytic findings; RIR estimations were significantly more accurate (i.e., attenuated tendency to under-predict) in the chest press compared to the leg press when RIR was predicted after the 10^{th} repetition in sets to failure. However, this significant difference was no longer present in a session 48 hours later in a similar study by the same group when two successive sessions were compared (43), potentially indicating that RIR accuracy differences between exercises attenuate with repeated exposure. Nonetheless, the general finding that lower body exercises are more susceptible to inaccuracy aligns with an earlier study by Hackett et al. (31) in which the average RIR-difference in the first set with 70% of 1RM was slightly higher in the squat (1.9 repetitions) compared to the bench press (1.3 repetitions). Further, another study by Hackett (44) reported slightly greater accuracy in the bench press compared to the squat: median error in RIR was similar in sets 1 and 2 (1 repetition), but bench press median RIR error improved to 0 repetitions in sets 3-5 whereas squat median RIR error was 0.5, 0, and 1 repetition in sets 3-5, respectively.

In addition to upper versus lower body exercise, different exercises within the upper or lower body may be inherently prone to greater inaccuracy. Mansfield et al. (15) reported meaningful intra-set RIR accuracy differences in favor of the barbell prone row compared to the bench press. For example, during the first set with 60% of 1RM, participants underestimated RIR by 7.0 repetitions for the bench press but only 3.1 repetitions for the prone row. For the lower body, this between-exercise difference was not observed by Odgers et al. (14) who compared the front squat and hex bar deadlift when participants completed four sets to failure and indicated when they felt they had four and one repetitions remaining on each, as the average RIR error for all intra-set ratings was 0.45 and 0.66 repetitions, respectively. Overall, there appears to be a tendency for lower body exercises to be more susceptible to inaccuracy; however, this conclusion may be exercise-specific as opposed to upper/lower body-specific (15). With that said, this conclusion is limited by the exercises studied in the available literature, and differences may attenuate with repeated exposure (43).

3) Set Number

Repeated exposure to RIR-based RPE ratings can also occur within a single training session. The meta-analysis by Halperin et al. (13) reported that set number moderated RIR-difference; that is, RIR ratings in later sets tended to be more accurate (although the effect was trivial). Indeed, Mansfield et al. (15) observed a relatively high RIR difference on the first set: an average RIR difference of 7.03, 2.20, 3.13, and 1.38 during 60% of 1RM bench press, 80% of 1RM bench press, 60% of 1RM prone row, and 80% of 1RM prone row, respectively. However, RIR-difference improved to less than 1 repetition for sets two and three in all conditions. A similar tendency is also present in the mentioned studies by Hackett et al. (31, 42, 43, 44). However, it is important to note that all these studies utilize a design in which load is fixed and RIR ratings are provided after a fixed number of repetitions. Thus, as fatigue accrues, the RIR ratings were made closer to failure, which may independently impact RIR rating accuracy. Odgers et al. (14) employed a different design in which participants indicated when they estimated RPE 6 and RPE 9, rectifying this limitation, and still reported that RIR error tended to decrease after the first set. For example, average RIR error decreased from 1.19 to 0.57 repetitions from the first to the second set during the 6 RPE call in the front squat. A potential reason later sets are more accurate may be due to practice and that sensations of fatigue from the previous set endpoint (i.e., momentary failure) can improve accuracy. Another possibility is due to within-session fatigue; later sets lead to less repetitions completed per set, which may have an independent effect on RIR rating accuracy.

4) Repetitions Per Set

The number of repetitions completed prior to momentary failure is influenced by training load, the fatigue present prior to starting a set, and individual differences in repetition performance at a given load. All these routes of modulating repetitions per set was included in a sub-group analysis by Halperin et al. (13), which indicated that RIR-difference was trivially moderated for sets with 1-12 repetitions and was strongly moderated for sets with 12+ repetitions. Only Mansfield et al. (15) and Lemos et al. (45) have investigated intra-set RIR ratings at varying intensities within an exercise. Specifically, Mansfield had participants report RIR in three sets to failure with 60% and 80% of 1RM in each the bench press and prone row. The RIR-difference in the first set provides the greatest insight on the isolated effect of load because set-to-set fatigue will differ between loads (17). Average RIR-difference reported by Mansfield et al. was considerably greater at 60% of 1RM compared to 80% of 1RM in both the bench press (7.03 ± 0.62 vs. 2.20 ± 0.37 repetitions) and the prone row (3.13 ± 0.84 vs. 1.38 ± 0.44 repetitions). Lemos et al. (45) compared RIR accuracy after the second repetition of sets with 50%, 70%, and 90% of 1RM in each the chest fly, seated leg extension, lat pulldown, lying leg curl, cable bicep curl, cable triceps extension, and shoulder press machine. Data were reported across all exercises at each load, and the average RIR difference decreased as load increased - approximately 8.8, 3.4, and -0.7 repetitions at 50%, 70%, and 90% of 1RM, respectively.

While varying load is an obvious way to modulate repetitions per set, the methodology employed in the series of studies by Hackett et al. (31, 42, 43, 44) provides insight into how set-to-set fatigue influences the number of repetitions completed. Since load was held constant in these studies, repetition performance decreased. For example, in the 2018 study by Hackett et al. (43), leg press repetition performance across sets 1-3 with 80% of 1RM was 17.5, 15.4, and 14.7 repetitions, respectively. This mechanism of decreased repetition performance coincides with an improvement in RIR rating accuracy; in this study, RIR error improved across sets 1-3 from 3.1 to 1.8 to 1.6 repetitions. Whether this improvement was due to reduced repetitions per set or increased set number cannot be conclusively determined.

The final way repetitions per set may vary is due to inter-individual differences in the number of repetitions that can be performed at a given load. Cooke et al. (11) examined repetition performance in trained participants at 70% of 1RM in the back squat and observed a wide range of 6-28 (mean: 14 ± 4). This may play an independent role in RIR rating accuracy; Zourdos et al. (16) observed a similar range of 9-26 repetitions (mean: 16 ± 4) with the same exercise and load and reported average absolute RIR-differences of 5.15 ± 2.92, 3.65 ± 2.46, and 2.05 ± 1.73 repetitions when subjects indicated 5 RIR, 3 RIR, and 1 RIR, respectively. Interestingly, there was a significant correlation between total repetitions performed and RIR-difference for the 5 RIR (r=0.65) and 3 RIR (r=0.56) calls, indicating that higher repetition sets are difficult to gauge RPE independent of load. Overall, reduced repetitions per set via all mentioned mechanisms (i.e., load, fatigue prior to the set, and individual repetition performance) appear to improve RIR rating accuracy. However, this notion requires further exploration based on when subject reported RIR predictions are made.

5) Proximity to Failure

The proximity to failure when RIR ratings are made also influences prediction accuracy; a sub-group analysis by Halperin et al. (13) indicated that RIR ratings provided later in a set (when a greater proportion of repetitions are complete) led to smaller RIR-differences. As mentioned, Mansfield et al. (15) reported greater RIR accuracy with 80% compared to 60% of 1RM. Importantly, predictions were made after the 8th repetition with 60% and after the 3rd repetition with 80% of 1RM. A 20% difference in load results in more than a 5 repetition difference in performance for most (40); thus, this study does not truly isolate the effects of load on RIR accuracy as it is confounded by the proximity to failure in which the ratings were made. As observed by Zourdos et al. (16), the average RIR-difference was considerably lower at closer proximities to failure: 5.15, 3.65, and 2.05 repetitions when subjects indicated 5, 3, and 1 RIR, respectively. Odgers et al. (14) employed a similar design and reported an average RIR error for RPE 6 of 1.38 repetitions compared to 0.18 repetitions for RPE 9. Similar to Mansfield et al., Lemos et al. (45) reported RIR accuracy for 50%, 70%, and 90% of 1RM, with all RIR ratings provided after the second repetition; thus, the fact that greater RIR accuracy was reported with higher loads was likely influenced by a closer proximity to failure when the ratings were made. Proximity to failure also played a role in the series of studies by Hackett et al. (31, 42, 43, 44) which reported improved RIR accuracy in later sets; as repetition performance decreased across sets, the RIR ratings (after a fixed number of repetitions) were inherently closer to failure. Overall, the actual proximity to failure in which RIR ratings are provided appears to influence RIR accuracy. However, this variable often coincides with set-to-set fatigue, or a greater load used, which may also play an independent role in RIR accuracy.

Limitations of Current Research

A primary limitation of current literature is the presence of multiple factors that may independently influence RIR-based RPE accuracy, making conclusions regarding individual factors tentative. Hackett et al. (43) reported improved RIR accuracy across sets 1-3 on the chest press and leg press, but the number of repetitions performed also decreased across sets. Since set number and number of repetitions per set each appear to influence RIR accuracy, the driving factor of this improvement cannot be determined. Similarly, Lemos et al. (45) reported improved RIR accuracy with higher loads, but ratings were provided after the second repetition; thus, this design does not isolate the factor of load as proximity to failure also varies. This same limitation is present in Mansfield et al. (15) - although RIR ratings were provided after repetition 3 with 80% of 1RM and repetition 8 with 60% of 1RM, this was not a sufficient difference to account for the 20% difference in load that likely led the 80% of 1RM RIR ratings to be made closer to failure (40). This is important because proximity to failure may be the variable that has the strongest support for influencing RIR accuracy. Indeed, Zourdos et al. (16) isolated this variable by utilizing a controlled load of 70% of 1RM while participants indicated when they predicted 5, 3, and 1 RIR. Notably, RIR rating accuracy improved by ~3 repetitions with 1 compared to 5 RIR. This study also reported a significant correlation between total repetitions performed and RIR error; however, these differences in total repetitions performed were due to individual differences in repetition performance at a given load. Thus, while this study demonstrates the role of proximity to failure on accuracy, it doesn't clarify the role of varying load.

Another limitation present in all intra-set RIR accuracy research is expectancy, i.e., the potential for participants' RIR ratings to become their goal for how many more repetitions to perform. Armes et al. (46) employed a novel deception design in which participants were told to train the knee extension until they predicted no more repetitions could be performed and then to momentary failure at a separate visit. The results indicated that subjects underpredicted their maximal number of repetitions by 2. This is greater than the average of 0.95 repetitions reported in the meta-analysis by Halperin et al. (13), potentially suggesting that intra-set ratings improve RIR accuracy. This is compounded by not all studies utilizing the same set endpoint definition (47); thus, designs not utilizing momentary failure may be more susceptible to inaccuracy.

Conclusion

Resistance training proximity to failure is an overlooked but important training variable that influences acute training fatigue and may influence longitudinal strength and hypertrophy adaptations (3, 17, 18). RIR-Based RPE is a valid method for quantifying proximity to failure and training prescription using it is effective (12, 27, 28, 31, 34). However, the utility of RIR-based RPE for training prescription and monitoring is dependent on the accuracy of the ratings. RIR ratings are generally underestimated by ~1 repetition, but there are many factors that may modulate this accuracy (13). These factors include the lifter's training experience, exercise performed, within-session set number, number of repetitions per set, proximity to failure when the RIR rating is made, and load.

Importantly, many of these variables have not been investigated independently. Specifically, there is a lack of clarity regarding RIR-based RPE accuracy with A) varying intensities when proximity to failure is constant and B) varying repetitions completed due to varying loads. A better understanding of these gaps in the literature will improve practical implementation of RIR-Based RPE and thus training outcomes.

III. METHODS

Experimental Design

The purpose of this study was to compare the accuracy of intraset RIR predictions made during sets with different repetition targets and relative load used (% of 1RM) in the squat and bench press. Further, this study examined the accuracy of RIR predictions made closer to failure (1 RIR) versus farther from failure (4 RIR).

Subjects reported to the laboratory a total of seven times over the course of 2.5 weeks. On day 1, pre-study testing was conducted for anthropometrics and 1RM back squat and bench press. Then, 48-72 hours later subjects began introductory training in week 1, which served to familiarize the subjects with procedures during three non-consecutive training days. Week 2 served as the main training week, in which subjects performed the squat and bench press three times per week and predicted intraset RIR during the last set of each training session.

Pre- and post-training nutrient timing was controlled. Subjects ingested a Branched Chain Amino Acid (BCAA) (BCAA, Core Nutritionals, LLC, Arlington, Virginia, United States of America, 22203) supplement containing 3.5g of leucine, 1.75g of Isoleucine, 1.75g of Valine (Ratio of 2:1:1), and 2.5g of glutamine 30 minutes prior to each testing and training session. Immediately following each training session, 42g of whey protein (Core Pro, Core Nutritionals, LLC, Arlington, Virginia, United States of America, 22203), containing 3.5g of leucine, was ingested by each subject. These quantities were selected as 3.5g of leucine is the threshold for maximally stimulating the muscle protein synthetic (MPS) response (48), which may augment adaptations to resistance training (49). Both BCAA and whey protein was consumed in powdered form with 10 oz. of water. Subjects were instructed to discontinue any other supplementation for the duration of the study.

Subjects

12 males between the ages of 18-40 were recruited. Subjects must have trained the back squat and bench press for at least 2 consecutive years as indicated on a physical activity questionnaire and be able to perform a 1RM back squat with ≥1.5 times body mass, and a 1RM bench press with ≥1.25 times body mass. Subjects with contraindications to exercise (i.e., hypertension, musculoskeletal injuries, etc.) as determined via a health history questionnaire were excluded. Prior to participation, all subjects provided written consent and the University's Institutional Review Board approved the study. Subject characteristics are summarized in Table 1.

Table 1: *Subject Characteristics*

Age (years)	Height (cm)	Body Mass (kg)	Body Fat Percentage	Squat 1RM (kg)	Bench Press 1RM (kg)	Training Age (years)
21.17 ± 2.48	174.69 ± 5.98	79.80 ± 7.02	11.58 ± 4.07	145.13 ± 23.77	106.17 ± 15.13	3.22 ± 1.56

Data are mean ± SD

Training Sessions

All subjects completed two weeks of training each consisting of three training sessions on non-consecutive days. Each week included an undulating periodized repetition target pattern of 10, 8, and 6 on sessions 1 (Monday), 2 (Wednesday), and 3 (Friday), respectively. At the completion of each set, subjects predicted RIR using the RIR-based RPE scale (Figure 1). Rest periods of 3-5 minutes were administered between all sets.

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

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*

Reprinted with permission from Zourdos et al., 2016.

Subjects performed reduced volume training with no sets to muscular failure in the introductory week (week 1). However, to familiarize subjects with the intraset RIR prediction procedures, subjects still predicted intraset RIR (at 4 and 1 RIR) during the final set of each session in week 1 if they reached these RIR values before achieving the repetition target. In week 2, subjects trained with the same repetition targets on each day as week 1, but with a lower RIR target (i.e., fewer repetitions remaining in the set) during each session. Further, the last set of each training session in week 2 was performed to failure, and subjects predicted when they believe they had 4 and 1 RIR during each set to failure. The details of all training sessions can be seen in Table 2.

Table 2: *Squat and Bench Press Training Protocol*

	Day 1	***Day 2***	***Day 3***
Week	*Protocol*	*Protocol*	*Protocol*
0	*N/A*	*N/A*	*Pre-Testing*
1	*1 set × 10 reps @ 6-8 RPE* *1 set × 10 reps @ 8-10 RPE*	*1 set × 8 reps @ 6-8 RPE* *1 set × 8 reps @ 8-10 RPE*	*2 sets × 6 reps @ 6-8 RPE* *1 set × 6 reps @ 8-10 RPE*
2	*2 sets × 10 reps @ 7-9 RPE* *1 set × ~10 reps @ failure**	*2 sets × 8 reps @ 7-9 RPE* *1 set × ~8 reps @ failure**	*3 sets × 6 reps @ 7-9 RPE* *1 set × ~6 reps @ failure**

*RPE = Rating of Perceived Exertion. *Subjects predicted 4 and 1 RIR during the set.*

Training Load Prescription and Adjustment

Investigators selected all loads during week 1. On all sets during week 1, barbell average concentric velocity ($m \cdot s^{-1}$) was recorded using the Open Barbell System Version 3 (Squats & Science, New York, N.Y., USA) (50) to aid in load selection, and subjects reported an RIR-based RPE after each set. Specifically, for the first set of session 1, barbell velocity and RIR-based RPE during warm-up sets as well a percentage of pre-testing 1RM (40) were used to inform load selection. On all other sets in week 1, subject-reported RIR-based RPE of previous sets in addition to barbell velocity and the apparent set difficulty were used by the investigators to inform load selection. Investigators explained their load selection decisions to subjects to further familiarize them with protocol expectations since subjects selected their own training loads in week 2.

Before each session in week 2, the following script was read to each subject while being shown the RIR-based RPE scale: "*Please view this scale to remind you of how RPE is scored. Today, working sets should fall within the RPE range of 7-9. Use your knowledge of your prior performances and how the warm-up sets felt to select a load you believe will fall within the assigned RPE range. The goal is to maintain your loads in a subsequent fashion, therefore, if the load you select falls above or below the target RPE range, an increase or decrease in load will occur on the next set. If you fall within the target RPE range, you have the freedom to increase or decrease load as you see fit so long as you believe this modified load will still fall within the target RPE range. Avoid being overly conservative or aggressive in your load selection and expect your RPE to rise with each set as fatigue accumulates.*" If the subject-reported RIR-based RPE prior to a non-failure set was under or over the desired range of 7-9, load was increased or decreased by 2% for every 0.5 RPE value from the range for the subsequent set in accordance with Helms et al. (27) (Table 3). Prior to the final set of each session in week 2, subjects were informed that the goal of the final set was to select a load that would lead to muscular failure after reaching the session's repetition target (e.g., failing repetition 11 if the repetition target is 10). If the second-to-final set was in the RPE 7-9 range, the participant selected the load for the final set per the instructions. If the RIR-based RPE for the previous set was under or over the desired RPE range of 7-9, load was adjusted in accordance with table 4.

Table 3: *Load Change Protocol for Non-Failure Sets in Week 2*

Previous Set Actual RPE	**Assigned RPE range: 7-9**
1	Increase load by 24%
2	Increase load by 20%
3	Increase load by 16%
4	Increase load by 12%
5	Increase load by 8%
6	Increase load by 4%
7	Participant choice
7.5	Participant choice
8	Participant choice
8.5	Participant choice
9	Participant choice
9.5	Decrease load by 2%
10	Decrease load by 4%

RPE = Rating of Perceived Exertion. Protocol from Helms et al. 2018.

Table 4: *Load Change Protocol for Failure Sets in Week 2*

Previous Set Actual RPE	**Assigned RPE: 11 (failure)**
1	Increase load by 36%
2	Increase load by 32%
3	Increase load by 28%
4	Increase load by 24%
5	Increase load by 20%
6	Increase load by 16%
7	Participant choice
7.5	Participant choice
8	Participant choice
8.5	Participant choice
9	Participant choice
9.5	Increase load by 2%
10	Maintain load

RPE = Rating of Perceived Exertion. Protocol adapted from Helms et al. 2018.

In the final set of each session in week 2, subjects performed a set to muscular failure during which they provided intraset predictions of 4 and 1 RIR.

Testing Procedures

Anthropometrics. Total body mass (kg) was assessed with a calibrated digital scale (Mettler-Toledo, Columbus, Ohio, USA) and height (cm) was measured via a wall-mounted stadiometer (SECA, Hamburg, Germany). Body-fat percentage was estimated using the average sum of two skinfold thickness measurements acquired from three sites (chest, abdomen, anterior thigh). If a second measurement at a given site was >2mm different than the previous measure, a third measurement was taken. The Jackson and Pollock equation (51) was used to estimate body-fat percentage, and the same investigator took all measurements.

Back Squat and Bench Press Technique. Both the back squat and bench press were performed in accordance with International Powerlifting Federation standards (52). Specifically, for the squat, subjects stood straight with the hips and knees locked, and the barbell placed across the upper back/shoulders. Upon the investigator's command of "squat" subjects descended 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. During the bench press, subjects laid supine on a weight bench, maintaining five points of contact (head, butt, and shoulders in contact with the bench, both feet flat on the floor throughout the movement). 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 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. All 1RM testing was performed in accordance with previously validated procedures (12). Specifically, all subjects completed a 5-minute dynamic warm-up followed by a squat-specific warm-up consisting of as many repetitions as desired with an empty barbell. Next, subjects performed 5 repetitions with 20% of their estimated 1RM, followed by 50% for 3 repetitions, 70% for 2 repetitions, and 80% for 1 repetition. Then, subjects were given 3-5 minutes of rest before performing a final warm-up at a load determined by the investigators (between 85-90% of estimated 1RM). Following the final warm-up, subjects took 5-7 minutes of rest while the investigators determined the load for the first 1RM attempt. Load was increased on each subsequent attempt until a 1RM was reached and 5-7 minutes of rest was given between each attempt. On every warm-up and 1RM attempt, RIR-based RPE and average concentric velocity was collected to aid in attempt selection. Following 1RM testing on the back squat, 10 minutes of rest was given and then an identical protocol was followed for the bench press. A 1RM was considered valid if one of 3 conditions were met: (a) subject reported a 10 on the RPE scale and the investigators determined an additional attempt with increased load would be unsuccessful, (b) subject reported a 9.5 RPE and failed the subsequent attempt with a load increase of 2.5 kg or less, or (c) subject reported a RPE 9 and failed the subsequent attempt with a load increase of 5 kg or less. Eleiko barbells and lifting discs (Chicago, Ill., USA) calibrated to the nearest 0.25 kg were used for all 1RM testing.

Repetitions to Failure and Intraset RIR Prediction. On the final set of squat and bench press in each session in week 2 (6 total sets), subjects performed a set to muscular failure during which they provided intraset RIR predictions of 4 and 1 RIR (Table 1). Muscular failure was defined as either 1) the subject was unable to complete a repetition and needed assistance in racking the barbell, or 2) the subject completed a repetition and was not comfortable attempting another. The procedures for the intraset RIR predictions were explained with the following script which was read to each subject before all 6 sets to failure during the study: "*The next set is the last set for squat/bench press today. We'll be taking this set until failure - if you complete a rep, we would prefer that you attempt another repetition if you are comfortable doing so. So, just focus on performing as many repetitions as possible, and we will spot you very closely. During the set, say 'NOW' when you feel like you have 4 reps remaining and when you feel like you have 1 rep remaining.*" The following reminders were also be provided to the subject prior to each failure set: *"Remember, let us know when you have 4 reps in the tank and 1 rep in the tank."*; *"Just focus on performing as many reps as possible and telling us your calls."*

Based upon the RIR predictions, both the predicted repetitions to failure at each called RIR and actual repetitions performed were recorded. Next, the difference between the actual and predicted repetitions performed (predicted repetitions - actual repetitions) was calculated as the RIR difference (RIRDIFF) for both RIR predictions. For example, if a subject said "now" for the first time during the failure set following the 6th repetition, then said “now” for the second time following the 10th repetition, that indicates the subject predicted they would go on to complete 10 total repetitions at the time of providing the 4 RIR prediction, and 11 total repetitions when providing the 1 RIR prediction. If the subject performed 12 total repetitions, then the RIRDIFF would be -2 repetitions for the 4 RIR prediction (10 predicted repetitions – 12 actual repetitions) and -1 repetition for the 1 RIR prediction (11 predicted repetitions – 12 actual repetitions).

Further, from the RIRDIFF both the “raw” and “absolute” RIRDIFF were calculated and used for analysis. The raw RIRDIFF accounted for directionality as described above. The absolute RIRDIFF utilized absolute values; for example, both an underprediction and overprediction by two repetitions was an absolute RIRDIFF of 2. In this way, the raw RIRDIFF indicated how much the RIR was under- or overpredicted, while the absolute RIRDIFF provided a true measure of accuracy (i.e., the overall average prediction error).

Statistical Analysis

One-way ANOVA was performed to compare actual repetitions performed across the 3 sessions for each bench press and squat. Paired-samples t-test was performed to examine differences between the RIRDIFF means at predicted 4 and 1 RIR. Factorial multivariate analysis of variance (MANOVA) with a Greenhouse Geisser correction for sphericity was used to examine RIR accuracy (i.e., RIRDIFF at predicted 4 RIR and 1 RIR) between each training session for each squat and bench press. The model controlled for the covariates of the session-type, number of repetitions performed in a set, and the load (percentage of 1RM) used during a set. Some RIRDIFF values were missing due to subjects forgetting to make an RIR prediction, which required the subject to be removed from the MANOVA for the entire session (e.g., forgot 1 RIR call but removed a 4 RIR call that was made). For this reason, factorial analysis of variance (ANOVA) was also used to examine RIR accuracy at predicted 4 RIR and 1 RIR for each squat and bench press with a larger sample size. Tukey's post hoc test was used for multiple comparison purposes and significance was set at $p \leq 0.05$. Both a "raw" analysis, which included both positive and negative values to indicate directionality of RIRDIFF (i.e., positive = overprediction, negative = underprediction), as well as an "absolute" analysis with the absolute value of all RIRDIFF values, were performed. Data are presented as mean ± standard error along with the associated 95% confidence intervals unless stated otherwise. SPSS version 28.0 (IBM, Armonk, NY) was used for analysis.

IV: RESULTS

One-Way ANOVA of Actual Repetitions Performed

Actual bench press repetitions performed were significantly greater in session 1 (9.60 ± 1.70) compared to session 2 (7.82 ± 1.60; $p = 0.024$) and session 3 (6.18 ± 0.98; $p < 0.001$). The difference between session 2 and session 3 was also significant ($p = 0.035$). For the squat, no between-session differences were significant. If a subject did not make either RIR prediction in a given set, the reps performed in that set were excluded. Mean ± standard deviation for each session is reported in table 5.

Table 5: *Actual Repetitions Performed*

Session	Mean	Standard Deviation	N
		Bench Press	
1	9.60*†	1.71	10
2	7.82‡	1.60	11
3	6.18	0.98	11
		Squat	
1	9.88	2.85	8
2	9.60	1.43	10
3	7.13	2.75	8

**= Significantly greater than session 2 (p = 0.024). †= Significantly greater than session 3 (p < 0.001). ‡ = Significantly greater than session 3 (p = 0.035). N = number of sets in which at least one RIR prediction was made and thus included.*

T-Test of 1 and 4 RIR and Individual Data

Across all sessions, the raw RIRDIFF was not significantly different at the predicted 4 RIR compared to the predicted 1 RIR in both the bench press (4 RIR: -0.06 ± 0.30 vs. 1 RIR: 0.31 ± 0.20; p = 0.055) and the squat (4 RIR: -0.29 ± 0.50 vs. 1 RIR: -0.36 ± 0.33; p = 0.403). However, the absolute RIRDIFF at the predicted 4 RIR was significantly greater than the predicted 1 RIR in both the bench press (4 RIR: 1.00 ± 0.18 vs. 1 RIR: 0.69 ± 0.12; p = 0.028) and the squat (4 RIR: 1.43 ± 0.31 vs. 1 RIR: 0.79 ± 0.26; p = 0.007), indicating that subjects predicted RIR more accurately when closer to failure.

Further, the raw RIRDIFF ± standard error for each individual subject and the associated 95% confidence intervals averaged across all 3 sessions can be seen in Table 6. The RIRDIFF for a session was only included if both the 4 RIR and 1 RIR call were made; thus, if a subject did not have any sessions for squat or bench press in which both the 4 RIR and 1 RIR call were made, their data are not included in table 6.

***Table 6**: Individual Subject Raw RIRDIFF Averaged for all Sessions*

Subject Number	RIR Difference	Std. Error	95% Confidence Interval Minimum	95% Confidence Interval Maximum	N
Bench Press Predictions Made at Predicted 4 RIR					
1	0.471	0.313	-0.334	1.275	3
2	0.655	0.881	-1.610	2.921	1
3	0.642	0.446	-0.504	1.788	3
4	0.347	0.328	-0.495	1.189	2

5	-1.105	0.318	-1.923	-0.286	3
6	0.072	0.432	-1.038	1.183	1
7	-0.763	0.300	-1.534	0.009	3
Bench Press Predictions Made at Predicted 1 RIR					
1	1.167	0.338	0.298	2.037	3
2	-1.163	0.953	-3.612	1.286	1
3	1.335	0.482	0.096	2.574	3
4	0.978	0.354	0.068	1.889	2
5	-1.704	0.344	-2.589	-0.819	3
6	1.665	0.467	0.464	2.865	1
7	-0.367	0.324	-1.201	0.466	3
Squat Predictions Made at Predicted 4 RIR					
1	-1.151	0.100	-1.158	-0.718	3
2	3.371	0.168	2.647	4.095	2
4	-6.499	0.292	-7.757	-5.242	1
5	-1.695	0.074	-2.014	-1.375	3
6	2.615	0.158	1.934	3.297	2
8	-3.521	0.196	-4.364	-2.678	1
9	-2.728	0.169	-3.455	-2.001	1
10	1.862	0.205	0.979	2.745	1
Squat Predictions Made at Predicted 1 RIR					

1	-0.538	0.796	-3.961	2.885	3
2	1.357	1.332	-4.372	7.086	2
4	-2.139	2.314	-12.095	7.818	1
5	-1.599	0.589	-4.131	0.934	3
6	1.597	1.253	-3.796	6.991	2
8	-0.873	1.551	-7.547	5.801	1
9	-0.464	1.338	-6.221	5.293	1
10	0.679	1.625	-6.311	7.669	1

RIR = Repetitions in Reserve. Negative values = Underpredicting RIR. Positive values = Overpredicting RIR. N = number of sessions in which both the 4 RIR and 1 RIR call were made and thus included.

Main Effects - MANOVA

The results of the MANOVA are presented below. However, as noted in Table 7 and 9, the sample sizes were as low as two for some sessions due to missing values. Therefore, following the MANOVA, a factorial ANOVA is presented with post-hoc analyses since the factorial ANOVA did not exclude the entire set if only 1 RIR call was missing.

For the bench press, none of the covariates significantly affected the raw RIRDIFF score. The specific p-values for the model are in Table 7.

Table 7: *Bench Press Raw RIRDIFF Covariates*

Covariate	RIR Prediction	Session 1 N	Session 2 N	Session 3 N	p-value
Session-Type	4 RIR	5	5	6	0.161

	1 RIR				0.087
Percentage of 1RM	4 RIR	5	5	6	0.908
	1 RIR				0.085
Total Repetitions Per Set	4 RIR	5	5	6	0.064
	1 RIR				0.198

RIR = Repetitions in Reserve.

Percentage of 1RM significantly affected the absolute RIRDIFF score in the bench press at the predicted 4 RIR. None of the other covariates were significantly related to the absolute RIRDIFF score. The specific p-values for the model are in Table 8.

Table 8: *Bench Press Absolute RIRDIFF Covariates*

Covariate	**RIR Prediction**	**Session 1 N**	**Session 2 N**	**Session 3 N**	**p-value**
Session-Type	4 RIR	5	5	6	0.113
	1 RIR				0.087
Percentage of 1RM	4 RIR	5	5	6	**0.047***
	1 RIR				0.085
Total Repetitions Per Set	4 RIR	5	5	6	0.361
	1 RIR				0.198

**Statistically significant (p < 0.05). RIR = Repetitions in Reserve.*

For the squat, the covariates session-type and percentage of 1RM significantly affected the raw RIRDIFF score at the predicted 4 RIR, but no covariates were significantly related to the raw RIRDIFF score at the predicted 1 RIR. No covariates significantly affected the absolute RIRDIFF score for predicted 4 or 1 RIR in the squat. The specific p-values for the raw RIRDIFF model are in Table 9.

Table 9: *Squat Raw RIRDIFF Covariates*

Covariate	RIR Prediction	Session 1 N	Session 2 N	Session 3 N	p-value
Session-Type	4 RIR	4	8	2	**0.003***
	1 RIR				0.255
Percentage of 1RM	4 RIR	4	8	2	**0.002***
	1 RIR				0.325
Total Repetitions Per Set	4 RIR	4	8	2	0.087
	1 RIR				0.971

**Statistically significant ($p < 0.05$). RIR = Repetitions in Reserve.*

Main Effects - Factorial ANOVA

For both the squat and bench press, no covariate significantly affected either the raw ($p = 0.085 - 0.971$) or absolute ($p = 0.085 - 0.518$) RIRDIFF at the predicted 1 RIR. However, there were significant findings at the predicted 4 RIR, which are presented below.

For the bench press at predicted 4 RIR, the covariates session-type and total repetitions per set significantly affected the raw RIRDIFF. Additionally, total repetitions per set affected the absolute RIRDIFF at the predicted 4 RIR in the bench press; however, the covariates session-type and percentage of 1RM did not. The specific p-values for the model are in Table 10 and 11.

Table 10: *Bench Press Predicted 4 RIR Raw RIRDIFF Covariates*

Covariate	**Session 1 N**	**Session 2 N**	**Session 3 N**	**p-value**
Session-Type	8	11	11	**0.028***
Percentage of 1RM	8	11	11	0.640
Total Repetitions Per Set	8	11	11	**<0.001***

**Statistically significant (p < 0.05). RIR = Repetitions in Reserve.*

Table 11: *Bench Press Predicted 4 RIR Absolute RIRDIFF Covariates*

Covariate	**Session 1 N**	**Session 2 N**	**Session 3 N**	**p-value**
Session-Type	8	11	11	0.584
Percentage of 1RM	8	11	11	0.596
Total Repetitions Per Set	8	11	11	**0.040***

**Statistically significant (p < 0.05). RIR = Repetitions in Reserve.*

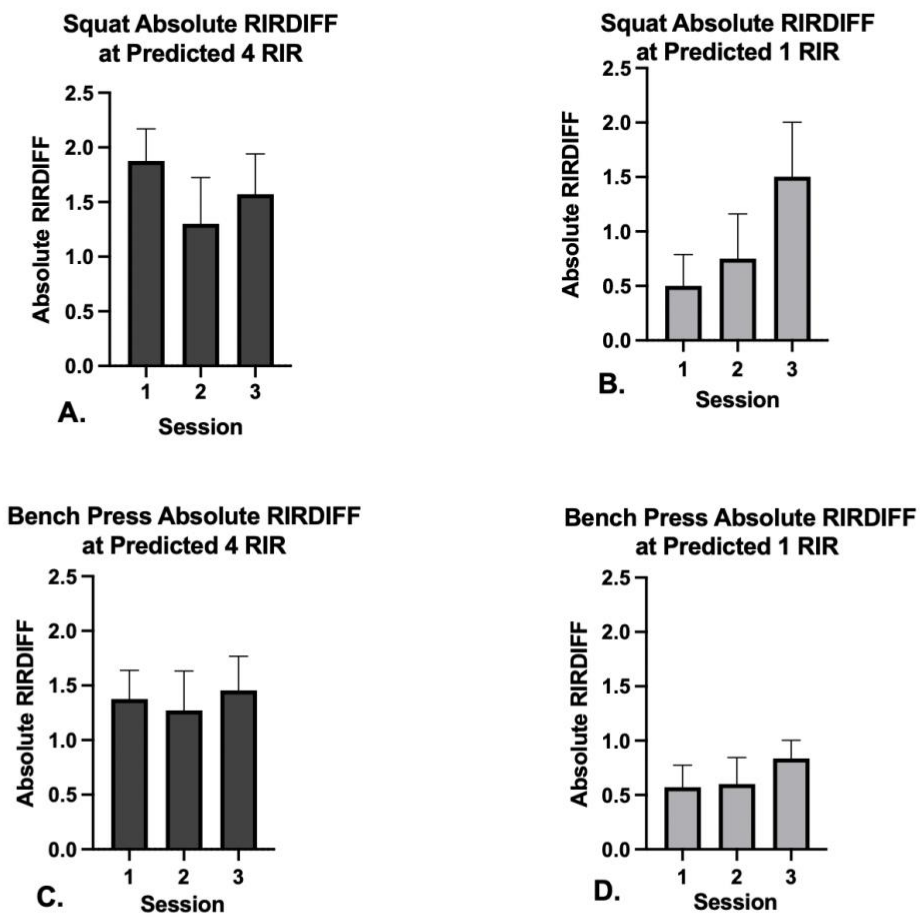
For the squat at the predicted 4 RIR, all covariates significantly affected the raw RIRDIFF. The specific p-values for the raw RIRDIFF at the predicted 4 RIR in the squat are in Table 12. However, none of the covariates significantly affected absolute RIRDIFF at the predicted 4 RIR, as can be seen along with all absolute RIRDIFFs by session in Figure 2ABCD.

Table 12: *Squat Predicted 4 RIR Raw RIRDIFF Covariates*

Covariate	**Session 1 N**	**Session 2 N**	**Session 3 N**	**p-value**
Session	8	10	7	**<0.001***
Percentage of 1RM	8	10	7	**<0.001***
Total Repetitions Per Set	8	10	7	**0.007***

**Statistically significant ($p < 0.05$). RIR = Repetitions in Reserve.*

Figure 2ABCD: *Absolute RIRDIFF Between Sessions for Each Call*



Data are Mean ± Standard Error.

Post-hoc analyses indicated the bench press raw RIRDIFF at predicted 4 RIR was significantly greater in session 1 (1.876 ± 0.405) compared to session 2 (0.551 ± 0.151; $p = 0.008$) and session 3 (-0.016 ± 0.317; $p = 0.014$). Further, the squat raw RIRDIFF at predicted 4 RIR was significantly greater in session 1 (1.072 ± 0.260) compared to session 2 (-0.358 ± 0.189; $p < 0.001$) and session 3 (-1.680 ± 0.351; $p = 0.014$), and the raw RIRDIFF was also greater in session 2 compared to session 3 ($p = 0.011$). The mean ± standard error raw RIRDIFF for each session can be seen in table 13.

Table 13: *Between-Session Comparison of Raw RIRDIFF Means*

Session Number	N	RIR Difference	Std. Error	95% Confidence Interval Minimum	95% Confidence Interval Maximum
Bench Press: Predictions Made at Predicted 4 RIR					
1	8	1.876*	0.405	1.014	2.739
2	11	0.551	0.151	0.229	0.874
3	11	-0.016	0.317	-0.691	0.659
Bench Press: Predictions Made at Predicted 1 RIR					
1	7	-0.775	0.427	-1.872	0.322
2	5	0.701	0.269	0.011	1.391
3	6	1.838	0.548	0.428	3.248
Squat: Predictions Made at Predicted 4 RIR					
1	8	1.072†	0.260	0.500	1.644
2	10	-0.358‡	0.189	-0.774	0.058

3	7	-1.680	0.351	-2.453	-0.906
Squat: Predictions Made at Predicted 1 RIR					
1	4	1.011	0.617	-1.643	3.665
2	8	-0.951	0.395	-2.650	0.749
3	2	-0.803	1.083	-5.461	3.855

*RIR = Repetitions in Reserve. Negative values = Underpredicting RIR. Positive values = Overpredicting RIR. *= significantly greater than session 2 ($p = 0.008$) and session 3 ($p = 0.014$). †= significantly greater than session 2 ($p < 0.001$) and session 3 ($p < 0.001$). ‡= significantly greater than session 3 ($p = 0.011$).*

IV: DISCUSSION

To our knowledge, this is the first study to compare the accuracy of intraset RIR predictions during sets with different repetition ranges due to differences in percentage of 1RM while controlling for the proximity to failure of the predicted RIR. Due to the mentioned small sample size in the MANOVA because of missing values (e.g., n = 2 for squat session 3; table 9), our discussion focuses on the results of the factorial ANOVA.

The main findings of this study were: 1) RIR accuracy was greater (i.e., lower absolute RIRDIFF) when made closer to failure in both the squat and bench press; 2) no covariates affected accuracy at predicted 1 RIR in the bench press or squat; 3) more repetitions per set led to greater underprediction of RIR at predicted 4 RIR; 4) as subjects progressed from session to session 3, the RIRDIFF at the predicted 4 RIR transitioned from overprediction to underprediction in both the squat and bench press. Therefore, our hypothesis that RIR predictions would be more accurate closer to failure was supported; however, our hypothesis that RIR predictions would be more inaccurate with higher repetition, lower load sets than with lower repetition, higher load sets was not supported.

The significantly more accurate RIRDIFF at predicted 1 RIR compared to predicted 4 RIR in both the squat and bench press is not surprising. Specifically, a meta-analysis from Halperin et al. (13) reported that RIR predictions became more accurate when made closer to failure. Further, individual studies found intraset RIR predictions on the squat (14, 16) and bench press (15) were more accurate closer compared to farther from failure. Specifically, Zourdos et al. (16) reported an RIRDIFF of 2.05 ± 1.73 when trained men predicted 1 RIR during a set of squats at 70% of 1RM and an RIRDIFF of 5.15 ± 2.92 at a predicted 5 RIR. Although the present study and findings from Zourdos et al. (16) agree that intraset RIR predictions are more accurate when made closer to failure, the absolute RIRDIFF in this study on the squat (4 RIR: 1.43 ± 0.31 vs. 1 RIR: 0.79 ± 0.26) was much lower (i.e., more accurate). One explanation for the more accurate values in the present study is that the subjects in Zourdos et al. (16) predicted RIR during higher repetition sets (14 ± 4 repetitions) than in the present study. Halperin et al. (13) reported that repetitions per set were related to RIR prediction accuracy; however, more repetitions were only trivially predictive of more inaccurate RIR when ≤12 repetitions were performed in a set. In the present study, subjects averaged 9.88 ± 2.85 repetitions in the highest repetition squat session. Another explanation for the far more accurate RIR predictions in the present study is that subjects in Zourdos et al. (16) predicted RIR during their first set whereas subjects in the present study predicted RIR in their third or fourth set; thus, they could have improved their RIR predictions via knowledge gained on the first few sets. Indeed, Mansfield et al. (15) observed that trained men made more accurate intraset bench press RIR predictions at 80% of 1RM on sets two, three, and four than on set one. Therefore, the low absolute RIRDIFF (i.e., accurate predictions) in the present study may be due to the fact that <12 repetitions, on average, were performed in each individual session and RIR predictions were made after the first set on both the squat and bench press.

The individual subject data (Table 6) show that although RIR accuracy was high at the group level, RIR accuracy at the individual level may vary. Interestingly, individual variation was greatest for the predicted 4 RIR on the squat (range: -6.499 ± 0.292 to

3.371 ± 0.168) while all other raw RIRDIFF estimated marginal means were less than ±2 repetitions for nine out of ten subjects. Further, the directionality of RIRDIFF appears to be individual; for example, at the predicted 1 RIR in the bench press, three subjects underpredicted RIR while four subjects overpredicted RIR. Therefore, our data suggest that individual variation of RIR accuracy may be exercise- and proximity to failure-dependent, and the directionality of error seems to be individual as well.

The main novelty in this study was examining if there was a difference in RIR prediction accuracy when repetitions per set changed as a function of load lifted. In the squat, the covariates session-type, percentage of 1RM, and repetitions per set were not significantly related to RIR accuracy (i.e., absolute RIRDIFF). As mentioned, a meta-regression from Halperin et al. (13) found that greater repetitions per set was related to lower RIR accuracy, but this relationship was only trivial when ≤12 repetitions were performed in a set. In the present study, subjects performed fewer than 12 reps, on average, in each session in the squat (session 1: 9.88 ± 2.85; session 2: 9.60 ± 1.43; session 3: 7.13 ± 2.75). Further, these differences in repetitions performed were not significantly different (Table 5). Therefore, our analysis indicates that repetitions per set as a function of load lifted within a narrow range does not significantly affect RIR accuracy in the squat.

In the bench press, only the covariate repetitions per set was significantly related to RIR accuracy (i.e., absolute RIRDIFF), and this was only at the predicted 4 RIR ($p = 0.040$). However, this was due to *greater* accuracy (i.e., lower RIRDIFF) in higher repetition sets. The covariate repetitions per set was also significantly related to RIR directionality (i.e., raw RIRDIFF) at predicted 4 RIR in the bench press ($p < 0.001$), and this was due to a tendency to overpredict RIR with lower repetition sets and a tendency to underpredict RIR with higher repetition sets. This general directionality does align with the meta-regression from Halperin et al. (13), which investigated raw RIRDIFF. Interestingly, the magnitude of overprediction with lower repetition sets was greater than the magnitude of underprediction with higher repetition sets, explaining the unexpected findings of greater accuracy (i.e., absolute RIRDIFF) in higher repetition sets in the bench press at predicted 4 RIR. Further, the tendency to overpredict with lower repetition sets and underpredict with higher repetition sets was present at predicted 4 RIR in the squat ($p = 0.007$), but the differences in magnitude were not of the same degree as the bench press. Overall, at predicted 4 RIR in both exercises, we observed a tendency to overpredict RIR with lower repetition sets and a tendency to underpredict RIR with higher repetition sets.

In addition to repetitions per set, the covariate session-type significantly affected raw RIRDIFF at predicted 4 RIR in both the bench press and squat. Interestingly, post-hoc analyses indicated that this relationship is due to the fact that raw RIRDIFF tended to be significantly lower (i.e., greater underprediction) in later sessions in which the repetition target was lower (Table 13). Halperin et al. (13) reported that *more* repetitions per set was related to a greater underprediction of RIR. However, their analysis indicated that repetitions per set up to 12 only trivially moderated this relationship. As noted, all sessions in the present study had an average number of repetitions <12; further, there was a small range of average repetitions for both bench press (3.42) and squat (2.75) across sessions 1-3. Given these factors, it seems that the session-dependent decrease in the raw RIRDIFF at the predicted 4 RIR may have been a function of the study design.

Specifically, subjects may have experienced a learning effect over the three sessions. After overpredicting RIR in session 1, subjects may have attempted to correct for this in sessions 2 and 3, which resulted in lower raw RIRDIFF values. This potential learning effect may be due to an order effect as the design did not include randomization. However, this lack of randomization also increases the ecological validity of the findings and suggests that trainees may attempt to correct mistakes in RIR prediction from session to session.

A shift in the directionality of RIR prediction error across sessions 1-3 was not present at predicted 1 RIR as no covariates significantly affected raw RIRDIFF at the predicted 1 RIR in the bench press and squat. Further, there was not a significant effect for any covariates on absolute RIRDIFF at predicted 1 RIR in either exercise. This lack of effect could be due to the inherent accuracy when RIR is predicted close to failure. For example, a meta-regression from Halperin et al. (13) reported that raw RIRDIFF tended to be <1 repetition when intraset RIR was predicted after ≥80% of the total repetitions in the set had been performed. In the present study, 26 out of 30 1 RIR predictions were made after ≥80% of the total repetitions in the set were performed, which probably accounted for the low raw RIRDIFF at the predicted 1 RIR (squat: -0.36 ± 0.33; bench press: 0.31 ± 0.20). Therefore, predicting RIR close to failure seems to be accurate when repetitions per set are <12.

Our study is not without limitations. First, subjects were required to volitionally indicate when they perceived a 4 RIR and 1 RIR; thus, some subjects forgot to predict an RIR which resulted in missing values. In addition to subjects forgetting, it is possible that the design created a systematic error towards underprediction at the 1 RIR prediction.

Specifically, our design did not account for a subject believing that they had >1 RIR but failing the next repetition. Second, the study was likely underpowered, and this was exacerbated by the MANOVA not including a subject unless they recorded both a 4 and 1 RIR call on an individual set. To combat this limitation, our analysis focused on a series of ANOVAs that included all calls made (e.g., a 4 RIR prediction was included even when a subject did not indicate a 1 RIR prediction). However, this approach increases the possibility of type I error. Third, our study was not a crossover design; thus, a learning effect (43) may have influenced RIR accuracy for sessions 2 and 3. Fourth, to ensure participant safety, some sets were terminated prior to concentric momentary failure if the subject was uncomfortable attempting another repetition and if the investigators determined another completed repetition was highly unlikely. Nonetheless, another repetition may have been possible in some cases, which would have changed the RIRDIFF. Fifth, since subjects knew the repetition target, RIR predictions may have been influenced by this. For example, this may have resulted in exaggerated inaccuracy when repetitions per set were different from the repetition target. Finally, it should be noted that our results are specific to trained young men in the back squat and bench press and may not apply to other populations and exercises.

Conclusion

Overall, our data agree with prior research that RIR prediction accuracy increases when predictions are made closer to failure. Furthermore, we did not observe a significant effect of any covariate on raw or absolute RIRDIFF at predicted 1 RIR in either exercise, which is possibly due to the fact that the RIR predictions were so accurate

(<1 repetition of error). Therefore, it seems that in sets of <12 repetitions, RIR predictions are accurate under various conditions when made close to failure. Although RIR prediction accuracy was significantly worse at the predicted 4 than 1 RIR, the absolute RIRDIFF at the predicted 4 RIR was also not significantly influenced by the covariates. However, this lack of relationship between the covariates and RIR accuracy far from failure (i.e., predicted 4 RIR) could be due to the fact that repetitions did not vary much between sessions. Specifically, the average number of repetitions per set changed by 2.75 repetitions on the squat from session 1 to 3 and by 3.42 repetitions on the bench press from session 1 to 3. We did observe that the raw RIRDIFF decreased throughout the week from session 1 to 3, indicating that subjects transitioned from overpredicting to underpredicting RIR throughout the week at the predicted 4 RIR. Further, we observed that RIR tended to be overpredicted with lower repetition sets and underpredicted with higher repetition sets at predicted 4 RIR.

Practically, coaches and practitioners can implement RIR-based training prescriptions when training close to failure and with <12 reps in a set and expect RIR to be predicted with high accuracy. For example, practitioners could be confident that a prescription of 3 sets × 10 repetitions to 1-2 RIR would result in accurate load selection. However, if training further from failure, lower repetition sets may be prone to overestimation of RIR and higher repetition sets may be prone to underestimation of RIR. Future research should investigate the effect of repetition range on RIR accuracy through a wider range of repetitions in a randomized crossover design with a larger sample size. Additionally, we encourage researchers to examine both absolute and raw RIRDIFF as the former indicates accuracy whereas the latter indicates directionality; thus, as seen in the present study, the results of these two values provide different conclusions.

APPENDICES

Appendix A: Approval Letter

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:	August 2, 2021
TO:	Michael Zourdos, Ph.D.
FROM:	Florida Atlantic University Health Sciences IRB
PROTOCOL #:	1422879-3
PROTOCOL TITLE:	[1422879-3] Effect of Proximity to Failure During Resistance Training on Muscle Performance and Fatigue
SUBMISSION TYPE:	Amendment/Modification
ACTION:	APPROVED
EFFECTIVE DATE:	July 19, 2021

Thank you for your submission of Amendment materials for this research protocol. The Florida Atlantic University IRB has approved your request to modify your protocol as outlined below:

- **Amendment involves research re-engagement plan for in-person research, COVID-19 safety precautions added**
- Adding two groups to the study, and increasing the number or participants to 50.

Please use the stamped, revised (consents, instruments, etc.) that accompany this approval letter.

- Protocol - ProximitytoFailureProtocol_clean.docx (stamped)
- Consent Form - ProximitytoFailureConsentFormAmendment_clean.docx (stamped)
- Other - Re-Engagement Resource 1 - COVID19 Screening Tool Proximity.docx (stamped)
- Other - Resource 3 - Consent Form Addendum_COVID-19 Safety Proximity.docx (stamped)

If you have any questions or comments about this correspondence, please contact Judith Martinez at:

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

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

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

Appendix B: Informed Consent

ADULT CONSENT FORM

Consent Form Version & Date: Version 2.0: July 6th, 2021.

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, Zac Robinson, B.S., CSCS

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
    - *Risks: None*
- 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
    - *Risks: None.*
- One repetition maximum (1RM) strength in the back squat and bench press.
    - *Time Point Tested: Pre- and Post-testing. Risks: muscle strains, soreness, joint aches, muscle soreness.*
- Three resistance training sessions per week on the squat and bench press with moderate to heavy loads
    - *Risks: muscle strains, soreness, joint aches, muscle soreness.*
- Ultrasound assessments of the quadriceps and chest to obtain muscle thickness
    - *Time Point Tested: Pre- and Post-testing. Risks: None*
- Height and weight assessments
    - *Time Point Tested: Pre- and Post-testing. Risks: None*
- Body composition by skinfold caliper (chest, abdomen, thigh)
    - *Time Point Tested: Pre- and Post-testing. Risks: None*
- Provide ratings of readiness (motivation to train, daily analysis of life demands, and perceived recovery status scales) prior to each training session
    - *Time Point Tested: Prior to each training session. Risks: None*
- Provide a rating of fatigue (session RPE scale) following each training session
    - *Time Point Tested: Prior to each training session. Risks: None*
- Undergo a 20 ml (4 teaspoons) blood draw prior to each testing and training session from a prominent vein on the forearm
    - *Time Point Tested: Prior to each testing and training session. Risks: infections, fainting, inflammation near the skin, collection site soreness and bruising, and unintended needle sticks.*

Consent_1_Adult Consent Template FAU/RI: Version 6.0 – 1/21/2019

FAU Institutional Review Board

1422879-3	
Approved On:	July 19, 2021
Expires On:	Not Applicable

- Consume branched chain amino acids and whey protein
    - *Time Point Tested: Prior to each training session. Risks: None*
- Delayed onset muscle soreness assessments through mild palpations of the quadriceps, hamstrings, and chest via an algometer prior to each training session
    - *Time Point Tested: Prior to each training session. Risks: Little to none (possible gastrointestinal distress)*
- ***Fast*** (no food or drink except for water) for at least two hours prior to all blood collections
    - *Prior to each training session. Risks: None*

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 5- to 7-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. In the event that your legs are not long enough for your feet to reach the floor we will provide raised wooden blocks for you to place your feet on. 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. Group's will be counterbalanced (i.e. statistical equal) in terms of your relative strength on the back squat and bench press and muscle size, thus you will be placed into a group based upon the strength and muscle thickness pre-testing measures. 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 skinfolds (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. There are five groups in this study, of which you will be assigned to one of them. Four of the groups will perform the same sets and repetitions of resistance training and only differ in terms of how close each set is taken to failure. One group will also be a specific proximity to failure but more sets and less repetitions per set will be performed. 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. In brief, it is a scale which assesses how many more repetitions you could do at the completion of a set. An RPE of 10 = 0 more repetitions, 9 = 1 more repetition, and so forth. Furthermore, you will be asked to fill out the Daily Analysis of Life Demands, which as basic questions regarding daily activities (i.e. How is your daily sleep?) in which you will answer "A" (better than normal), "B" (normal) or "C" (worse than normal) along with a 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. The perceived recovery status scale is a 0-10 scale with 0 indicating poorly recovered and 10 indicating very well recovered. The motivation to train scale is a 0-10 scale with 0 indicating not motivated at all and 10 indicating highly motivated. You will also be asked to complete a session rating of perceived exertion scale following each training session, which is a 0-10 scale in which 0 indicates that you feel as though you are at "rest" and 10 indicates that you feel you just produced "maximal" exertion. Each 0-10 scale will take no more than 30 seconds, and the daily analysis of life demands scale will take no more than 5 minutes. Additionally, prior to each training session and following each training session you will be asked to consume branched chain amino acids containing 3.5 grams of the amino acids leucine and 30 grams whey protein, respectively in a powder mixed with water. These supplements will be from the Company Core Nutritionals and they are being provided since the timing of protein and amino acid intake around exercise has been shown to affect muscle strength and growth responses. Therefore, you will receive these supplements to ensure appropriate pre- and post-exercise nutrition. The supplements will be products of the Company Core Nutritionals, which the company will be providing for the study. 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 RPE Training Group

@ 4-6 RPE Group	*Day 1*	*Day 2*	*Day 3*
Week	*Protocol*	*Protocol*	*Protocol*
0	*N/A*	*N/A*	*Pre-Testing*
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	*3 sets x 4 reps @ average load used on this day between weeks 2-6*	*3 sets x 2 reps @ average load used on this day between weeks 2-6*	*Post-Testing*

Table 2: 4-6 RPE RVM Training Group

@ 4-6 RPE RVM Group	Day 1	Day 2	Day 3
Week	Protocol	Protocol	Protocol
0	N/A	N/A	Pre-Testing
1 - Intro	S: 3 sets x 6 reps @ 66.7%	S: 4 sets x 4 reps @ 71.7%	S: 6 sets x 3 reps @ 75.5%
	B: 3 sets x 6 reps @ 72.0%	B: 4 sets x 4 reps @ 75.0%	B: 6 sets x 3 reps @ 79.1%
2	S: 5 sets x 6 reps @ 70.9%	S: 6 sets x 4 reps @ 75.8%	S: 8 sets x 3 reps @ 79.7%
	B: 5 sets x 6 reps @ 77.0%	B: 6 sets x 4 reps @ 79.7%	B: 8 sets x 3 reps @ 83.7%
3	S: 5 sets x 6 reps @ 73.4%	S: 6 sets x 4 reps @ 78.2%	S: 8 sets x 3 reps @ 83.0%
	B: 5 sets x 6 reps @ 77.3%	B: 6 sets x 4 reps @ 81.7%	B: 8 sets x 3 reps @ 85.5%
4	S: 5 sets x 5 reps @ 73.7%	S: 7 sets x 3 reps @ 82.8%	S: 10 sets x 2 reps @ 87.1%
	B: 5 sets x 5 reps @ 81.0%	B: 7 sets x 3 reps @ 84.4%	B: 10 sets x 2 reps @ 88.0%
5	S: 5 sets x 5 reps @ 80.5%	S: 7 sets x 3 reps @ 85.2%	S: 10 sets x 2 reps @ 88.4%
	B: 5 sets x 5 reps @ 81.6%	B: 7 sets x 3 reps @ 85.2%	B: 10 sets x 2 reps @ 88.8%
6	S: 6 sets x 4 reps @ 83.7%	S: 9 sets x 2 reps @ 91.4%	S: 8 sets x 2 reps @ 92.8%
	B: 6 sets x 4 reps @ 84.1%	B: 9 sets x 2 reps @ 88.2%	B: 8 sets x 2 reps @ 92.1%
7	S: 6 sets x 4 reps @ 84.8%	S: 9 sets x 2 reps @ 88.8%	S: 8 sets x 2 reps @ 94.5%
	B: 6 sets x 4 reps @ 80.8%	B: 9 sets x 2 reps @ 89.2%	B: 8 sets x 2 reps @ 94.5%
8 - Taper	S: 4 sets x 2 reps @ 78.5%	S: 6 sets x 1 rep @ 83.0%	Post-Testing
	B: 4 sets x 2 reps @ 79.8%	B: 6 sets x 1 rep @ 84.3%	

*RVM = Relative Volume Matched to the 7-9 RPE group
S = Squat; B = Bench Press
Any subject in this group that exceeds RPE 6 will reduce the % of 1RM.

Table 3: 7-9 RPE Training Group

@ 7-9 RPE Group	Day 1	Day 2	Day 3
Week	Protocol	Protocol	Protocol
0	N/A	N/A	Pre-Testing
1 - Intro	2 sets x 10 reps @ 6-8 RPE	2 sets x 8 reps @ 6-8 RPE	3 sets x 6 reps @ 6-8 RPE
2	3 sets x 10 reps @ 7-9 RPE	3 sets x 8 reps @ 7-9 RPE	4 sets x 6 reps @ 7-9 RPE
3	3 sets x 10 reps @ 7-9 RPE	3 sets x 8 reps @ 7-9 RPE	4 sets x 6 reps @ 7-9 RPE
4	3 sets x 9 reps @ 7-9 RPE	3 sets x 7 reps @ 7-9 RPE	4 sets x 5 reps @ 7-9 RPE
5	3 sets x 9 reps @ 7-9 RPE	3 sets x 7 reps @ 7-9 RPE	4 sets x 5 reps @ 7-9 RPE
6	3 sets x 8 reps @ 7-9 RPE	3 sets x 6 reps @ 7-9 RPE	4 sets x 4 reps @ 7-9 RPE
7	3 sets x 8 reps @ 7-9 RPE	3 sets x 6 reps @ 7-9 RPE	4 sets x 4 reps @ 7-9 RPE
8 - Taper	3 sets x 4 reps @ average load used on this day between weeks 2-6	3 sets x 2 reps @ average load used on this day between weeks 2-6	Post-Testing

Table 4: 7-9 RPE+ Training Group

@ 7-9 RPE+ Group	Day 1	Day 2	Day 3
Week	Protocol	Protocol	Protocol
0	N/A	N/A	Pre-Testing
1 - Intro	1 set x 10 reps @ 7-9 RPE, 1 set of ~10 reps @ 8-10 RPE	1 set x 8 reps @ 7-9 RPE, 1 set of ~8 reps @ 8-10 RPE	2 sets x 6 reps @ 7-9 RPE, 1 set of 6 reps @ 8-10 RPE
2	3 sets x 10 reps @ 7-9 RPE*	3 sets x 8 reps @ 7-9 RPE*	4 sets x 6 reps @ 7-9 RPE*
3	3 sets x 10 reps @ 7-9 RPE*	3 sets x 8 reps @ 7-9 RPE*	4 sets x 6 reps @ 7-9 RPE*
4	3 sets x 9 reps @ 7-9 RPE*	3 sets x 7 reps @ 7-9 RPE*	4 sets x 5 reps @ 7-9 RPE*
5	3 sets x 9 reps @ 7-9 RPE*	3 sets x 7 reps @ 7-9 RPE*	4 sets x 5 reps @ 7-9 RPE*

6	*3 sets x 8 reps @ 7-9 RPE**	*3 sets x 6 reps @ 7-9 RPE**	*4 sets x 4 reps @ 7-9 RPE**
7	*3 sets x 8 reps @ 7-9 RPE**	*3 sets x 6 reps @ 7-9 RPE**	*4 sets x 4 reps @ 7-9 RPE**
8 - Taper	*1 set x 4 reps @ 6-8 RPE, 1 set of ~4 reps @ 8-10 RPE*	*1 set x 3 reps @ 6-8 RPE, 1 set of ~3 reps @ 8-10 RPE*	*Post-Testing*

* indicates that the last set (i.e., third or fourth) will be taken to failure.

Table 5: Failure Training Group

@ 10 RPE Group	*Day 1*	*Day 2*	*Day 3*
Week	*Protocol*	*Protocol*	*Protocol*
0	*N/A*	*N/A*	*Pre-Testing*
1 - Intro	*2 sets x 10 reps @ 7-9 RPE*	*2 sets x 8 reps @ 7-9 RPE*	*3 sets x 6 reps @ 7-9 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	*3 sets x 2 reps @ average load used on this day between weeks 2-6*	*3 sets x 2 reps @ average load used on this day between weeks 2-6*	*Post-Testing*

Additionally, during all weeks (weeks 1-8) you will be asked to perform the following assistance exercise movements after the squat and bench press: barbell shoulder press, barbell row, biceps curls, triceps extensions, and dumbbell lateral raise. The barbell shoulder press and row will be performed on days 1 and 3 each week, while the biceps curls, triceps extension, and dumbbell lateral raise will be performed on day 2 of each week. These exercises will be performed with the same sets and repetitions as the squat and bench press, however, all groups will train these exercises to a proximity to failure of an 8RPE. These lifting exercises are not being tested at pre- and post-testing in the study, rather they are just being performed so that you can train the musculature of the full-body that is usually trained in resistance training programs. Additionally, immediately following each training session, subjects will complete a scale assessing effort for each session (session RPE scale). Furthermore, we will do 3 random 24 hour dietary recalls during the pre- and post-testing weeks as trained by a registered dietitian.

Lastly, prior to both testing and training days we will ask to draw a 20 milliliter (4 teaspoons) 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). The biomarkers are enzymes which are commonly elevated in response to muscle damage. Therefore, by taking blood samples and measuring these biomarkers prior to each training session we will be able to examine how recovered you are, in terms of muscle damage, prior to each training session. 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 four 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.***

Participation in this study will in no way affect your grade in any course.

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

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

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

Additionally, there are possible minor risks anytime there is a collection of blood. These risks include: infections, fainting, inflammation near the skin, and collection site soreness and bruising. 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.

Further, the scales in this study provide no risk. The supplements in this study provide little to no risk. These supplements are widely used in exercise and are safe. However, in the very unlikely event that you develop any gastrointestinal distress from the supplementation, we will discontinue supplementation for the duration of the study.

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.

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Approved On:	July 19, 2021
Expires On:	Not Applicable

- 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) <u>Consent Statement:</u> *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: ____________________

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COVID-19 SAFETY CONSENT FORM ADDENDUM

FAU has established the re-engagement of certain in-person studies. This document contains additional information regarding the safety precautions being implemented in order to resume in-person research during the current COVID-19 environment.

Safety Precautions

To ensure everyone's safety, our research team is taking the following precautions to protect our participants and research team to help slow the spread of the coronavirus:

- *Subject will be required to wait outside until their exact starting time to minimize people in the laboratory*
- *Hand sanitizer will be provided to all subjects upon entering the laboratory*
- *In accordance with both FAU and CDC guidelines all unvaccinated investigators will wear masks at all times and all unvaccinated subjects will wear masks when entering the lab and when the exercise protocol is over (i.e., the subjects will not be required to wear masks when exercising).*
- *Physical distancing will be maintained in accordance with CDC guidelines except when investigators need to "spot" the subject during resistance training for safety.*
- *All equipment will be immediately sanitized after being used*
- *All equipment will be sanitized each day after that day's data collection has been completed*

Protecting Yourself and Others

To participate in the research, you agree to take certain precautions which will help keep everyone safer from exposure, sickness, and possible death. As a research participant, you acknowledge and understand that additional safety precautions where the in-person research activities are occurring are incorporated and included in this consent addendum. If you are unable to adhere to these safeguards, you must not participate in the research. To participate, you are agreeing to:

- Complete the screening tool and only participate if you are symptom free
- If you have other symptoms of the coronavirus beyond what is included in the screening tool or are otherwise feeling unwell, you should cancel or reschedule
- Wait in your car or outside [or in a designated waiting area until no earlier than 5 minutes before our appointment time.
- Practice good hygiene, which includes, but is not limited to, washing your hands or using alcohol-based hand sanitizer when you enter the building
- Adhere to the safe distancing precautions we have set up in the waiting area and testing/lab space.
- Wear a mask at all times and in all areas of the research site, unless directed by a member of the research study team.
- Avoid physical contact (such as shaking hands)
- Avoid touching your face or eyes with your hands. If you do, please immediately wash or sanitize your hands

Contact Tracing

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If you participate in an in-person research study and within 14 days discover that you are COVID-19 positive or learn that you came into contact with or cared for someone who has tested COVID-19 positive, you must contact the researcher with this information.

Risks

By participating in this study, you are agreeing to meet face to face with the safety measures in place.

If at any time you decide you do not feel comfortable participating in person, you can withdraw from the study and leave at any time without penalty. If you have safety concerns about the research procedures or space, call or email the investigator(s) mzourdos@fau.edu at_(301) 580-7536 or the Office of Research Integrity at researchintegrity@fau.edu or the AVP for Research Integrity at 561-297-2318. Note due to remote work email is the fastest way to reach the office.

You understand that although safety measures have been put into place, by participating in this research study, there is a risk of exposure to the coronavirus. This risk may increase if you travel by public transportation, cab, or ridesharing service.

Consent Statement:

I have read or had read to me and understand the information describing the safety practices for this study. All my questions have been answered to my satisfaction. I am 18 years of age or older and agree to the safety procedures outlined in this COVID-19 safety consent form addendum. 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 addendum.

Printed Name of Participant:____

Signature of Participant:______________________________________ Date: ______________

Printed Name of Person Obtaining Consent:____

Signature of Person Obtaining Consent:_____________________ Date:___________________

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Version 1 – 3/8/2021

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

1

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?

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