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# Effect of the Repetitions-In-Reserve Resistance Training Strategy on Bench Press Performance, Perceived Effort, and Recovery in Trained Men

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## Abstract

Mangine, GT, Serafini, PR, Stratton, MT, Olmos, AA, VanDusseldorp, TA, and Feito, Y. Effect of the repetitions-in-reserve resistance training strategy on bench press performance, perceived effort, and recovery in trained men. *J Strength Cond Res* 36(1): 1–9, 2022—This study examined the effects of the repetitions-in-reserve (RIR) strategy on resistance exercise performance, perceived effort, and recovery. Fourteen resistance-trained men (24.6 ± 3.0 years, 176 ± 5 cm, 85.7 ± 14.0 kg) completed 2 bench press protocols in a randomized crossover fashion. The protocols consisted of 4 sets at 80% of 1 repetition maximum (1RM) to a self-reported 3-RIR and a fifth set to failure or all 5 sets to failure (0-RIR). Barbell kinetics (velocity, rate of force development, and impulse), repetition volume, total work, and ratings of perceived exertion (RPE) were quantified on each set. Barbell kinetics were reassessed during one set of 3 repetitions at 80% 1RM completed at 24-hour, 48-hour, and 72-hour postexercise. Blood samples were collected before and after exercise at 6 hours, 24 hours, 48 hours, and 72 hours and analyzed for concentrations of creatine kinase (CK). Separate, 2-way repeated-measures analysis of variance revealed significant interactions ($p < 0.001$) where 3-RIR better maintained repetitions and work at greater average velocity (+0.6 $m \cdot s^{-1}$) and lower RPE (0-RIR = 10; 3-RIR = 8.2) across all sets. No differences were seen between conditions for CK at 6 hours postexercise (3-RIR: 32.2 ± 55.3%; 0-RIR: 40.8 ± 66.0%) or for CK and barbell kinetics at 24 hours to 72 hours postexercise. Although no differences were seen for recovery, the RIR strategy enabled work to be better sustained across sets at a lower perceived effort and higher average velocity. This strategy could be used to manage fatigue and better sustain effort and volume during a resistance training session.

**Key Words:** volume load, creatine kinase, barbell velocity, ratings of perceived effort, rate of force development, muscle failure

## Introduction

Resistance training can be used to improve a variety of physical and athletic characteristics, but its effect is w on the specific programming strategy. A strategy's effect is determined, at least in part, by how well and specifically the acute programming variables are manipulated to emphasize muscle fiber activation and fatigue (30,36). Traditionally, muscle fiber activation is believed to be dictated by the training load's proximity to the individual's 1 repetition maximum (1RM) (30,34,36). However, it may also be enhanced when lower-intensity efforts are repeated over multiple sets with short recovery periods or sustained to the point of momentary muscular failure (9,21). Although different strategies may emphasize one over the other (i.e., activation or fatigue), the overall amount of volume or work completed seems to be an essential consideration for stimulating adaptations (29,30,34,36). Training volume is quantified by the number of exercises that activate a particular muscle group, the number of sets and repetitions completed for those exercises, and the frequency in which these muscle groups are trained. Of interest, completing sets to momentary muscular failure is a strategy that can enhance training volume by maximizing the number of repetitions completed on each set.

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Momentary muscular failure occurs when the trainee cannot correctly complete another concentric muscle action during a set without assistance (39). Performing consecutive repetition maximum (RM) sets (i.e., to failure) ensures that an overload stimulus is present and that effort is consistent. However, compared with nonfailure sets, RM sets require greater effort and produce more discomfort, inflammation, and muscle damage (13,24,27,28,33). These may negatively affect adherence to the training program and require a longer recovery. Although muscle damage is commonly expected to increase protein synthesis (7,11,36), the effect declines with repeated bouts and may be more relevant to the muscle fiber repair process than improvements in size and strength (11). Thus, the benefit of completing sets to failure is questionable.

Performing RM sets may also fail to produce the desired amount of volume during both the training session and week because of fatigue and damage delaying the recovery process (17,18). Across a variety of intensity and rest interval configurations, performing consecutive RM sets with limited recovery has led to a significant reduction in repetitions completed on subsequent sets (33,37,38) and movement velocity for up to 48 hours (27,28). Although these findings suggest that the practice may be detrimental, most studies directly comparing the utility of RM sets were completed with novice or recreational trainees (5,24,26,31). Less experienced trainees generally sustain more damage and still respond favorably to a multitude of training stimuli (11,30). As their "window of adaptation" shortens, more specific strategies become necessary to stimulate continued adaptations (30). Even in experienced lifters, although, it may be more prudent to strategically use sets to failure (e.g., on the final set) to help preserve volume across multiple sets and the training week while confirming maximal stimulation and activation of the musculature (17,18).

Manipulating a set's proximity to momentary muscular failure may be a strategy to help manage fatigue and recovery while still providing a sufficient stimulus. This strategy can be related to the recently proposed concept of "stimulating repetitions" (3). An idea suggesting that the most important repetitions are those that involve high-threshold motor units contracting at slower speeds because of either the force-velocity relationship or fatigue. In practice, this would refer to the final 2–4 repetitions at higher loads (>5 RM) or the last 5 repetitions at lower-intensity loads. Research related to these concepts formally refers to a set's proximity to failure as repetitions-in-reserve (RIR) (15–17,40). The RIR strategy requires the trainee to conclude a set once they sense that they cannot complete more than a specific number of additional repetitions within that set. Although this strategy seems to be a valid and accurate prescription tool (15,17,35,40), particularly in more experienced trainees (35), only a few studies have examined its effect compared with other strategies (2,14,16). Of these, a pair of studies have provided evidence of the RIR strategy being comparable with (if not better than) percentage-based training for improving muscle size, strength, and performance (14,16). However, to the best of our knowledge, only one study has compared the RIR strategy with RM sets (2). Areda et al. (2) reported greater strength and comparable power improvements in the bench press strength, as well as comparable gains in back squat strength following RIR-based (RIR = 3) compared with RM-based training in female, youth basketball players during their competitive season. Still, there is much to learn about this strategy and its effect on performance and recovery immediately after an acute bout of resistance exercise. Therefore, the purpose of this study was to examine the effects of using RIR or RM prescription during an acute bout of bench press on total training volume, performance recovery, perceived effort, and muscle damage in resistance-trained men. Because others have observed a benefit in these measures when complete RM sets were cut in half (e.g., completing only 5 repetitions with a 10 RM load) (13,27,28), we expect a similar outcome when experienced trainees are asked to specifically conclude sets at approximately 3 repetitions short of failure.

## Methods

### Experimental Approach to the Problem

Participation in this randomized, crossover study required a total of 11 visits to the University's Exercise Physiology Laboratory (EPL). Subjects were scheduled for their baseline visit on the conclusion of the 5-day loading phase where they would provide a pre-exercise blood sample and complete assessments of body composition and muscular strength and endurance in the bench press. The subjects returned to the EPL within 3–7 days to provide an additional pre-exercise blood sample and then randomly complete one of 2 acute, bench press protocols: 5 sets at 80% 1-RM where all sets were taken to momentary muscular failure (0-RIR) or when 4 sets were taken to approximately 3 repetitions short of failure and one final set to failure (3-RIR). The subjects returned to the EPL at 6 hours, 24 hours, 48 hours, and 72 hours postexercise to provide additional blood samples and complete one set of 3 repetitions in the bench press at 80% 1RM. Subsequently, the subjects returned to the EPL 1 week later to repeat these procedures using the alternate bench press protocol. The subjects refrained from exercise (outside of the study) and alcohol for 24 hours before any visit (48 hours before their baseline visit), and they maintained their normal dietary intake and caffeine consumption habits (verified by 24-hour dietary food logs) throughout the entire study. Perceived effort was quantified following each set of the 2 acute bench press protocols, whereas barbell kinetics were measured on each repetition completed in the study. Blood samples were analyzed for circulating concentrations of creatine kinase (CK). Comparisons were made between protocols for completed repetitions and work, perceived effort, and changes in barbell kinetics and CK concentrations.

### Subjects

Subject characteristics measured at baseline are presented in Table 1. A *priori* analysis using a moderate effect size (f = 0.25) for a repeated measures design with a minimum of 8 time points indicated 14 subjects were needed for this study. As such, 14, college-aged men, who resistance trained on at least 3 sessions per week for the past year and possessed resistance training experience (≥3 years; 7.6 ± 3.7 years) were recruited for and enrolled into this study. According to the health and physical activity questionnaire they completed before enrollment, the subjects reported training with the bench press exercise on 2.3 ± 1.3 sessions per week, averaging 5.6 ± 3.1 working sets for 7.9 ± 2.1 repetitions over the past 6 months. In addition, between-set rest intervals were tracked by 10 of the 14 subjects, and they reported 1.4 ± 0.5 minutes as their average break. Enrolled subjects were also required to demonstrate their ability to meet the United States Powerlifting Association–Class III strength standards in the bench press (1) on their baseline visit. In brief, Class III competitors can lift 1.0–1.3 times their body mass in the bench press based on the standards for the relevant weight classes of the present sample (i.e., 60–125-kg). The present sample was able to lift between 1.1–1.4 times their body mass in the bench press. All subjects were free of any injury or illness that would have affected their ability to exercise (as determined by the health and physical activity questionnaire) and verified that they had never consumed any illegal performance enhancing substances. This investigation was approved by the Kennesaw State University's institutional review board (#18-512).

No subjects were under the age of 18 years. Following a description of the study's purpose, procedures, risks, and benefits, resistance-trained men provided their written informed consent.

**Table 1**
**Subject baseline characteristics.***

| | Mean ± *SD* | Range |
|---|---|---|
| Age (y) | 24.6 ± 3.0 | 21.2–30.0 |
| Height (cm) | 176 ± 5 | 168–185 |
| Body mass (kg) | 85.7 ± 14.0 | 58.9–111.5 |
| Body fat percentage (%) | 19.3 ± 7.6 | 8.5–34.4 |
| Fat-free mass (kg) | 66.4 ± 8.8 | 51.4–82.9 |
| 1RM bench press (kg) | 127 ± 23 | 93–184 |
| 80% 1RM bench press (kg) | 102 ± 19 | 75–147 |

*1RM = 1 repetition maximum.

Before enrollment, it was expected that several potential subjects would indicate that they regularly or periodically consumed creatine monohydrate as a dietary supplement. To standardize supplementation, all subjects initiated a 5-day creatine monohydrate loading phase on their enrollment followed by maintenance dosages for the remainder of the study.

### Procedures

*Creatine Monohydrate Supplementation.* To standardize creatine monohydrate consumption, subjects were given a 5-day supply (twenty 5 g packets for a total of 100 g) of creatine monohydrate in powder form (BulkSupplements, Hard Eight Nutrition, LLC, Henderson, NV) on their enrollment. The subjects were instructed to consume four 5 g packets with water (375 ml) per day for 5 days to standardize muscle creatine content (23). On completing the baseline visit, the subjects were provided with an additional 100 g (twenty 5-g packets) of creatine monohydrate to maintain muscle creatine content for the remainder of the investigation. For this maintenance phase, the subjects were instructed to ingest one 5-g packet of creatine monohydrate per day with water (375 ml) until they completed the study. To ensure compliance, the subjects were asked to return all emptied packets on each visit to the EPL.

*Body Composition Testing.* The subjects wore athletic clothing and removed their shoes and jewelry/metal for all body composition testing. Initially, body mass (kg) and height (cm) were measured using a stadiometer and an electronic physician's scale (Tanita Corporation of America, Inc.; Arlington Heights, IL). Then, the subjects laid supine on a dual-energy X-ray absorptiometry (DXA; Lunar iDXA, General Electric Healthcare, Madison, WI) scanning table. Total body estimates of percent fat (%) and fat-free mass (kg) were determined from an entire body scan in a "standard" mode using the company's recommended procedures and supplied algorithms. Quality assurance was assessed by daily calibrations performed before all scans using a calibration block provided by the manufacturer. All DXA measurements were performed by the same researcher using standardized subject positioning procedures. All body composition data were used for descriptive purposes.

*Muscular Strength and Endurance Testing.* After a general warm-up consisting of riding a cycle ergometer for 5 minutes at a self-selected resistance and pace, the subjects completed a warm-up specific to the bench press on a weightlifting rack with the safety bars set at a height that would prevent the barbell from making uncontrolled contact with the subject's torso, neck, or head. The specific warm-up consisted of 5 submaximal sets of 8, 3, 2, 1, and 1 repetition(s) with loads equating to 50, 60, 70, 80, and 90% of their estimated 1RM, respectively. The subjects were then allotted 3–5 one repetition sets to find the highest load they could successfully lift while maintaining proper form. Barbell kinetics were monitored during each maximal attempt, whereas subjects were asked to subjectively rate perceived effort (RPE) and RIR on each attempt during rest periods. Rest intervals were 2–3 minutes for warm-up sets and 3–5 minutes for maximal attempts.

Proper technique for the bench press was defined by the subjects' grip and hand placement, their ability to maintain 5-point contact, and their demonstration of control throughout the entire lift. The subjects were instructed to use a pronated grip that was at least standard width (i.e., approximately shoulder width), but no wider than double the width of their shoulders. Their chosen grip placement during 1RM assessment was measured by tape measure, recorded, and enforced for all remaining bench press repetitions in this study. Throughout the lift, a repetition was discarded if the subject did not maintain contact between their feet and the floor, as well as between their buttocks, shoulders, and head with the bench while lying supine. All repetitions began with the subjects holding the barbell above their chest with their elbows fully extended. At their ready, they lowered the barbell to their chest in a controlled fashion and then on touching their chest, immediately pressed the barbell back to the starting position. The subjects were instructed to perform the concentric portion of the lift as fast as possible. A researcher was located laterally to the subject to monitor technique during all maximal attempts and discard any attempt that did not meet technical standards. The 1RM was identified when the subject successfully completed an attempt, and then, scored it as an RPE = 10, RIR = 0, or average concentric barbell velocity was less than $0.10\ m\cdot s^{-1}$ (19). If the subject was unable to complete a repetition at a given load, they were allowed one additional attempt at that load. If the second attempt was not successful or if the subject declined a second attempt, the load was reduced to 50% of the difference between it and the last successful 1 repetition set.

After 1RM testing and a 10-minute rest period, the subjects completed a single, repetition maximum set of the bench press at 80% 1RM. The same technical standards described for 1RM testing were enforced during this assessment. The assessment concluded when one of the following 3 criteria was met: (a) the subject reached a point during the concentric portion of a repetition where barbell velocity was zero or negative for at least 2 seconds, (b) the subject could no longer complete a repetition with proper technique, or (c) the subject could not complete a repetition without assistance from a researcher. Once again, barbell kinetics were monitored during this assessment and the subjects were asked to quantify RPE and RIR after the assessment. The test served to familiarize subjects with a repetition maximum set and estimate the expected repetition count during the first working set of each acute bench press protocol. All muscular strength and endurance tests were completed under the supervision of a certified strength and conditioning specialist (CSCS) and a trained spotter.

*Subjective Measures.* Throughout the study, subjects were asked to provide an RPE and RIR scores after all sets during testing and the acute bench press protocols. The Borg category ratio (0–10) scale was used to subjectively measure perceived effort put forth during the set (4). Its inverse, the RIR (0–10) scale, was used to quantify the subject's perceived number of repetitions they could have completed had they not stopped the set (17). Proper utilization of these scales was described to subjects during enrollment. In brief, subjects were instructed that within the RIR scale, a maximal effort lift would be considered RIR = 0, which would correspond to RPE = 10. That is, they would have put forth maximal effort and would not be able to perform an additional repetition without assistance. Likewise, RIR = 3 would indicate that the subject could have completed an additional 3 repetitions during the set without assistance, and this would correspond to RPE = 7. Subjects were familiarized with the use of these scales during all warm-up sets before testing, and their usage continued through muscular strength and endurance testing. During muscular strength and endurance testing, these scales were used to assist in load adjustment between maximal attempts and to help

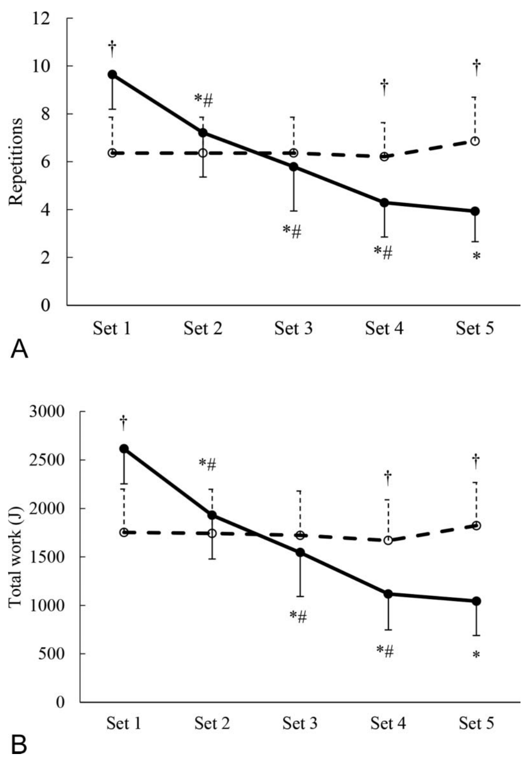


**Figure 1.** Repetition (A) and work (B) differences between acute bench press conditions and sets (mean ± *SD*). Note: Close circles and solid line = 0-RIR; open circles and dashed line = 3-RIR; *significantly ($p < 0.05$) different from set 1; #significantly ($p < 0.05$) from the previous set; †significant ($p < 0.05$) difference between protocols. RIR = repetitions-in-reserve.

determine the 1RM and to familiarize subjects with their use in association with performing a set to muscular failure. Their usage after each set of the acute bench press protocols served to verify that sets were either completed as a repetition maximum or were concluded with approximately 3 repetitions remaining for 0-RIR and 3-RIR, respectively.

*Barbell Kinetics Measurement.* Barbell kinetics were monitored during every bench press repetition completed in this study using a linear position transducer (Tendo Weightlifting Analyzer; TENDO Sports Machines, Trencin, Slovak Republic). The transducer was placed on the ground directly beneath the barbell's starting position and connected to the barbell by an extended cable. The positioning of the transducer was such that the extended cable's angle was approximately 90° to the ground, which helped to minimize its horizontal displacement during each repetition. Data from every repetition was collected by the TENDO Unit Computer Software Version PA (v6.06, TENDO Sports Machines). The software's display was used to monitor real-time barbell velocity during testing to assist in 1RM determination and identify the conclusion of the repetition maximum set. Data collected during each acute exercise protocol and performance recovery session were downloaded onto a spreadsheet (Excel, v. 365, Microsoft, Redmond, WA) for treatment. In brief, each file reported displacement (mm), velocity ($m \cdot s^{-1}$), and force (N) values collected every 5 ms throughout each repetition. Any data related to the descent of the barbell (towards the chest) could be identified by negative velocity values at either the onset of each repetition (i.e., eccentric phase) or within the repetition (due to fatigue). Data related to the eccentric phase or failed repetitions were discarded from analysis. Otherwise, each set of positive velocity values was used to verify the number of counted repetitions and averaged to calculate average concentric velocity (ACV). Meanwhile, their associated displacement, force, and time-stamp values were used to calculate work (force × displacement), impulse (force × time), and average rate of force development (RFD, peak force $x$ time$^{-}$×).

*Blood Sampling and Biochemical Analysis.* Pre-exercise blood samples were collected on the baseline visit, each acute bench press protocol session (i.e., 0-RIR and 3-RIR), as well as on each performance recovery visit (at 24 hours, 48 hours, and 72 hours postexercise). A postexercise sample was collected 6 hours after the completion of each acute bench press protocol. All samples were obtained from an antecubital vein using a needle by a research team member who was trained and experienced in phlebotomy. Approximately 10 ml of blood was drawn into SST tubes (for serum collection) and allowed to clot for 10 minutes before centrifugation at 3,600 rpms at 4° C. The resulting serum was aliquoted and stored at −80° C until analysis.

All samples were analyzed for circulating concentrations of CK ($\mu \cdot L^{-1}$), a known biomarker of muscle damage (11,13,27,28). Concentrations were determined against an enzymatic approach in serum samples using commercially available reagents (Pointe Scientific) and a single-cuvette spectrophotometer (SpectraMax M3 Multi-Mode Microplate Reader, Molecular Devices, San Jose, CA) at a wavelength of 340 and 450 nm, respectively. To eliminate interassay variance, all samples were thawed once and analyzed in triplicate in the same run by a single technician with an average coefficient of variation of 4.7%.

*Acute Bench Press Protocols.* Each acute bench press protocol session began with 5 minutes of riding a cycle ergometer at a self-selected resistance and pace followed by a specific warm-up. The specific warm-up consisted of 4 submaximal sets of 10, 8, 6, and 3 repetitions with loads equating to 40, 50, 60, and 70% 1RM. Subsequently, the subjects were randomly assigned to complete either 3-RIR or 0-RIR using a load equal to 80% 1RM on each set. This load was selected because of its use in other studies on this topic (13,27,28,33) and to limit repetition counts on any set from greatly exceeding 10 repetitions (i.e., the maximum value of the RIR scale) (17,34). During 3-RIR, the first 4 sets were stopped by the subject when he perceived that no more than 3 repetitions were possible (RIR = 3; RPE = 7). Estimation of the expected repetition count for the first set of 3-RIR was facilitated by the subject's performance during initial muscular endurance testing. On the fifth and final set (i.e., RPE = 10; RIR = 0) of 3-RIR, as well as during all 0-RIR sets, the subjects completed a repetition maximum using the same criteria and technical standards described for muscular strength and endurance testing. After each set, 3–4 minutes of rest was allotted, during which, the subjects were asked to provide an RPE and RIR score for the completed set.

*Performance Recovery Assessment.* Recovery in barbell kinetics was monitored at 24 hours, 48 hours, and 72 hours postcompletion of each acute bench press protocol. The same standardized warm-up procedures described for the acute bench press protocols were followed for each of these sessions. Subsequently, the subjects completed one set of 3 repetitions using a load equal to 80% of 1RM using the same technical requirements described for muscular strength and endurance testing. This volume was

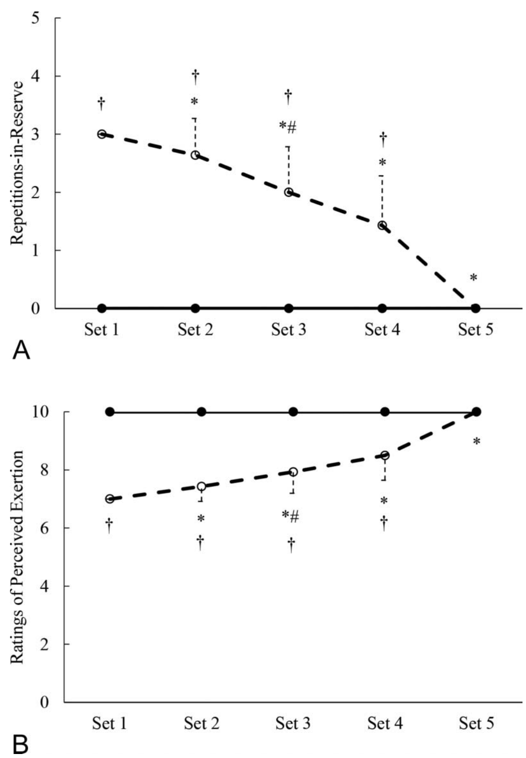


**Figure 2.** Differences between acute bench press conditions for repetitions-in-reserve (A) and ratings of perceived effort (B) (mean ± *SD*).Close circles and solid line = 0-RIR; open circles and dashed line = 3-RIR; *significantly ($p < 0.05$) different from set 1; #significantly ($p < 0.05$) from the previous set; †significant ($p < 0.05$) difference between conditions. RIR = repetitions-in-reserve.

selected to limit fatigue and make comparisons to barbell kinetics collected on the first 3 repetitions from the first set of either acute bench press protocol.

*Dietary Compliance.* The subjects were instructed to refrain from alcohol consumption for 24 hours before any visit (48 hours before their baseline visit) and to maintain their normal dietary intake habits throughout the study. To facilitate compliance, the subjects were given a paper dietary food log at the completion of their baseline visit. They were instructed to record all food and beverage intake for 24 hours before their next visit (i.e., the first acute bench press protocol session) and then to follow the same diet for each 24-hour period preceding all remaining visits. To assist with their compliance, the subjects were also instructed to take photographs of their meals and forward them to a password-protected email account that was created solely for the purpose of this study. All food logs and photographs were visually inspected by the same researcher to verify compliance.

### *Statistical Analyses*

The assumption of normality was initially verified by the Shapiro-Wilk test. Then, separate two-way (condition × set) analyses of variance (ANOVA) with repeated measures were performed to compare the acute effects of 0-RIR to 3-RIR on training volume, total work, ACV, RPE, and RIR. A one-way repeated measures ANOVA was used to determine if differences existed in CK concentrations at baseline and before exercise on 0-RIR and 3-RIR. Between-protocol differences in the recovery of barbell kinetics (ACV, RFD, and impulse) and percent changes in CK from pre-exercise were examined by separate two-way (protocol *x* time) repeated-measures ANOVA. The Greenhouse-Geisser adjustment to degrees of freedom was applied when the assumption of sphericity was violated. Interpretations of effect size were evaluated (8) at the following levels: small effect (0.10), medium effect (0.25), and large effect (>0.40). Following any significant interaction, separate one-way repeated-measures ANOVA with Bonferroni correction was performed to assess pairwise differences between time points within each acute bench press protocol. Pairwise differences between protocols for each set were assessed by separate paired-samples *t*-tests. A criterion alpha level of $p \leq 0.05$ was used to determine statistical significance. All data are reported as mean ± *SD*. Statistical Software (V. 26.0, SPSS, Inc., Chicago, IL) was used for all analyses.

## Results

### *Acute Bench Press Protocol Performance*

Differences between bench press conditions for repetitions and work completed across 5 sets are illustrated in Figure 1. Significant interactions (condition *x* set) were observed for repetitions ($F = 48.8$, $p < 0.001$, $\eta_p^2 = 0.79$) and work ($F = 43.6$, $p < 0.001$, $\eta_p^2 = 0.77$), where the 3-RIR group maintained similar repetitions and work across all 5 sets. By contrast, 0-RIR elicited a 60% decline ($p < 0.001$) in repetitions and work from the first (9.6 ± 1.5 repetitions, 2,615 ± 360 J) to fifth set (3.9 ± 1.3 repetitions, 1,043 ± 354 J). Although 0-RIR completed more ($p < 0.001$) repetitions and work on set 1 (3.3 ± 1.3 repetitions, 862 ± 323 J), less ($p < 0.001$) was completed on sets 4 (−1.9 ± 1.3 repetitions, −552 ± 349 J) and 5 (−2.9 ± 1.7 repetitions, −779 ± 446 J). However, the main effects for overall differences between conditions were not significant for total repetitions (0-RIR = 30.9 ± 6.8 repetitions; 3-RIR = 32.1 ± 6.3 repetitions; $p = 0.367$) or total work (0-RIR = 8,249 ± 1655 J; 3-RIR = 8,708 ± 1751 J; $p = 0.236$).

Differences between conditions for RIR and RPE scores reported after each set are illustrated in Figure 2. Significant interactions (condition × time) were observed for RIR ($F = 81.3$, $p < 0.001$, $\eta_p^2 = 0.86$) and RPE ($F = 83.0$, $p < 0.001$, $\eta_p^2 = 0.87$), where RIR and RPE did not change for 0-RIR across all 5 sets. By contrast, 3-RIR experienced a significant decline ($p < 0.001$) in RIR and RPE from the first (RIR = 3; RPE = 7) to fifth set (RIR = 0; RPE = 10), and differences ($p < 0.001$) were noted for both RIR and RPE on each set except the fifth set. The main effects for overall differences between conditions indicated more RIR (1.8, $p < 0.001$) at a lower RPE (−1.8, $p < 0.001$) for 3-RIR compared with 0-RIR across 5 sets.

Changes in ACV across 5 sets during each condition are illustrated in Figure 3. Although significant main effects for condition ($F = 29.3$, $p < 0.001$, $\eta_p^2 = 0.75$) and set ($F = 26.5$, $p < 0.001$, $\eta_p^2 = 0.73$) were observed, only a trend for an interaction was found for ACV ($F = 2.58$, $p = 0.052$, $\eta_p^2 = 0.21$). On average, ACV was greater during 3-RIR (0.35 ± 0.05 m*second$^{-1}$) than it was for 0-RIR (0.30 ± 0.04 m·s$^{-1}$) across all 5 sets. Compared with set 1, ACV was slower during both conditions on set 3 (−0.06 m·s$^{-1}$, $p = 0.008$), set 4 (−0.07 m·s$^{-1}$, $p = 0.002$), and set 5 (−0.09 m·s$^{-1}$, $p < 0.001$).

### *Performance Recovery*

Averaged barbell kinetics during each condition and through the following 72 hours are presented in Table 2. No differences were observed between 0-RIR and 3-RIR. Only main time effects ($p < 0.05$) were noted for ACV and impulse, averaged ACV was greater at 72 hours compared with both acute protocols ($p = 0.012$) and 48 hours postexercise ($p = 0.031$). Averaged impulse decreased from 48 hours to 72 hours after both acute protocols ($p = 0.019$).

No significant differences were seen in CK concentrations ($F = 0.5$, $p = 0.640$, $\eta_p^2 = 0.04$) before exercise at baseline (59.2 ± 52.3 $\mu\cdot L^{-1}$), 0-RIR (72.1 ± 54.7 $\mu\cdot L^{-1}$), and 3-RIR (85.5 ± 97.4 $\mu\cdot L^{-1}$). Likewise, neither a main effect for condition ($F = 0.8$, $p = 0.394$, $\eta_p^2 = 0.06$) or an interaction ($F = 0.9$, $p = 0.430$, $\eta_p^2 = 0.06$) was observed for percent changes in CK. Only a main effect for time was seen ($F = 5.5$, $p = 0.008$, $\eta_p^2 = 0.29$), where CK concentrations were elevated ~36.5% after 6 hours ($p = 0.009$) and remained elevated by ~36.9% after 48 hours ($p = 0.010$). Percent changes in CK over the 72-hour recovery period after each condition are illustrated in Figure 4.

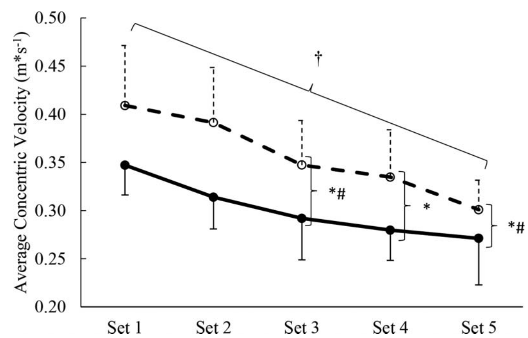


**Figure 3.** Changes in average concentric barbell velocity during each acute bout of bench press (mean ± SD). Close circles and solid line = 0-RIR; open circles and dashed line = 3-RIR; *significantly ($p < 0.05$) different from set 1; #significantly ($p < 0.05$) from the previous set; †significant ($p < 0.05$) difference between conditions. RIR = repetitions-in-reserve.

## Discussion

This study aimed to determine whether performing sets to momentary muscular failure or a self-reported 3-RIR during an acute bout of bench press elicited advantages in training volume and performance, perceived effort, and recovery. Compared with RM sets, previous studies reported similar (or improved) training volume and recovery at lower perceived effort when trainees ended sets after half of the expected repetitions (2–6 repetitions) for a given RM load (4–12 RM) were completed (13,27,28). Thus, it was hypothesized that similar advantages would be present when resistance-trained men were asked to conclude sets after they sensed that no more than 3 complete repetitions were possible. The data suggest that total repetitions and work completed, damage sustained (indicated by CK concentrations), and recovery were similar between 0-RIR and 3-RIR, but 3-RIR better maintained repetitions and work across each set and performed repetitions with greater ACV and lower perceived effort.

More repetitions and work were completed on the first set of 0-RIR, but these progressively declined across all remaining sets. By conserving repetitions on the first 4 sets, 3-RIR better maintained their repetition count across all sets (~1.5–1.8 times more repetitions over the final 2 sets) at ~22.9% lower RPE. The decline in repetition count for 0-RIR and maintained repetition count for 3-RIR at lower perceived effort were consistent with previous reports (13,27,28,33). Although this has not resulted in appreciable differences in total repetitions or work, collective findings are limited to their quantification over 1–2 exercises (i.e., bench press only, back squat only, or bench press followed by back squat). From a practical standpoint, this limits applicability because workouts are not generally limited to a single or couple exercise(s), and adaptations are more dependent on the total amount of work completed for all related exercises within an entire workout or series of workouts. That said, a few longitudinal studies have shown slight advantages for muscle growth and performance from using nonfailure sets compared with RM sets (2,5,24). However, only one of those studies actually used the RIR strategy (2) and none are ideal for comparative purposes. Arede et al. (2) observed greater strength improvements in teenage, female basketball players when they concluded sets with 10RM loads at RIR = 3, and equal improvements (to RM sets) were seen in measures of speed, agility, and power. Still, the athletic characteristics and training experiences of those young women, which are likely to influence RIR accuracy (35) and training outcomes (30,36), are not comparable with those of the present sample. Meanwhile, Lacerda et al. (24) divided the total number of repetitions completed during RM sets equally across nonfailure sets and Carrol et al. (5) simply compared RM ranges (e.g., 4–6 RM) with fixed percentages and repetitions (e.g., 70% 1RM for 5 repetitions). Neither placed the onus on the subject to conclude sets after sensing their approach to failure, a limitation that was also present in related acute studies (13,27,28,33). Nonfailure sets in most acute studies were instead concluded when half of the expected repetitions for a given RM load had been completed (e.g., 5 repetitions using a 10RM load) (13,27,28), making the presence of overload questionable. This study expands on previous works by demonstrating equal volume may be completed at lower perceived effort when experienced trainees ended initial sets after sensing their proximity to failure was within 3 repetitions before completing one final RM set.

Another interesting facet about performing nonfailure sets has been their effect on barbell velocity. Compared with RM sets, previous studies have reported 9–25% greater barbell velocity during half-RM sets (13,28) and 14–18% greater velocity when resistance-trained women (~4.5 years) concluded 10-RM machine squat sets after velocity had slowed by 20% (33). Maintaining greater movement velocity during training is believed to be useful for improving RFD and mechanical power (10,20,25) and incorporating this practice into a traditional resistance training scheme may have a more comprehensive effect on various strength characteristics (20,25). Indeed, Carroll et al. (5,6) noted greater improvements in muscle size, strength, power, and endurance from 10 weeks of training that used percentage-based, nonfailure sets versus RM sets. In this study, both conditions required the concentric portion of all repetitions to be performed "*as fast as possible*" (i.e., with ballistic intent) to regulate effort and better observe each condition's effect on barbell velocity; a previously used surrogate for measuring fatigue and recovery (13,27,28,33). The data indicated that ACV was approximately 19.6% greater during 3-RIR compared with 0-RIR, despite within-set velocity declining by 39.0 and 40.2% under both conditions, respectively. These between-group differences and within-set decrements seem to be on par with previous reports (13,28,33), although within-set decrements during 0-RIR were less severe than those seen in physically-active, college-aged men using similar relative bench press loads (i.e., 8–12 RM elicited 58.6–69.6% decline in barbell velocity) (13,28); a difference that

**Table 2**
**Seventy-two-hour recovery of barbell kinetics averaged across the first 3 repetitions after each acute bench press condition.***

| | Set 1 | 24 h | 48 h | 72 h | Condition | | | Time | | | Condition × time | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | F | *p* | $\eta_p^2$ | F | *p* | $\eta_p^2$ | F | *p* | $\eta_p^2$ |
| Velocity ($m \cdot s^{-1}$) | | | | | | | | | | | | | |
| 0-RIR | 0.45 ± 0.05 | 0.43 ± 0.06 | 0.45 ± 0.06 | 0.47 ± 0.06†‡ | 0.1 | 0.785 | 0.01 | 5.3 | 0.023 | 0.29 | 0.3 | 0.743 | 0.03 |
| 3-RIR | 0.45 ± 0.07 | 0.43 ± 0.03 | 0.45 ± 0.04 | 0.48 ± 0.04†‡ | | | | | | | | | |
| RFD ($N^* s^{-1}$) | | | | | | | | | | | | | |
| 0-RIR | 7,865 ± 2,919 | 7,481 ± 1,688 | 7,867 ± 2,270 | 8,208 ± 2,683 | 1.9 | 0.192 | 0.13 | 2.1 | 0.165 | 0.14 | 0.1 | 0.888 | 0.01 |
| 3-RIR | 8,173 ± 2,731 | 7,754 ± 2003 | 7,925 ± 2,272 | 8,362 ± 2,582 | | | | | | | | | |
| Impulse (N*s) | | | | | | | | | | | | | |
| 0-RIR | 616 ± 71 | 681 ± 172 | 635 ± 121 | 604 ± 80‡ | 2.7 | 0.124 | 0.17 | 5.3 | 0.024 | 0.29 | 0.6 | 0.539 | 0.05 |
| 3-RIR | 612 ± 88 | 634 ± 73 | 628 ± 87 | 581 ± 67‡ | | | | | | | | | |

*RIR = repetitions-in-reserve; RFD = rate of force development.
†Significantly ($p < 0.05$) different from the first set of each respective condition.
‡Significantly ($p < 0.05$) from the previous time point.

might be attributed to the greater strength and training age of the present sample.

Despite the differences in repetition and work distribution, barbell velocity, and perceived effort, the severity and recovery of damage, estimated by CK concentrations, were the same for both conditions. This does not agree with previous studies where RM sets led to greater CK elevations and a slower recovery compared with ending sets before momentary muscular failure (13,27,28). Compared with this study, CK concentrations have been reported to be ~70.2% and ~67–257% greater at 6 (27) and 48 hours postexercise (13,27,28), respectively. However, the lack of agreement may be related to differences between our study's workout protocol and others'. In past studies, subjects completed 3–6 sets of bench press and back squats at 8–10 RM loads for RM or half-RM within the same session (13,27,28). Although evidence of training specific muscle groups affecting CK concentrations is limited, completing more work seems to have a mild effect (22). The training status of the present sample may also have contributed to this disagreement. Except for the well-trained men (8.2 ± 3.5 years) who participated in the study by Morán-Navarro et al. (27), subject training experience was comparatively less (<4 years) in past studies on this topic (13,28). Greater elevations in CK are common in less-experienced trainees, and this can be further modified by the number of exposures one has to a specific stimulus (22). Although subject training habits leading up to past studies was not made clear (13,27,28), the men involved in this study reported training typically with a similar (to this study's protocol) number of sets and repetitions for shorter rest intervals over the past 6 months. That familiarity might explain the lower CK values seen in this study (11). Moreover, it was uncommon for their resistance training sessions to only include a single exercise. Thus, their experience with greater volume loads may have had a protective effect against damage induced by this study's protocol and limited our ability to observe differences between conditions (11). Finally, it is possible that the final RM set of 3-RIR, paired with 4 near-maximal sets, was sufficient to match the damage produced by 0-RIR.

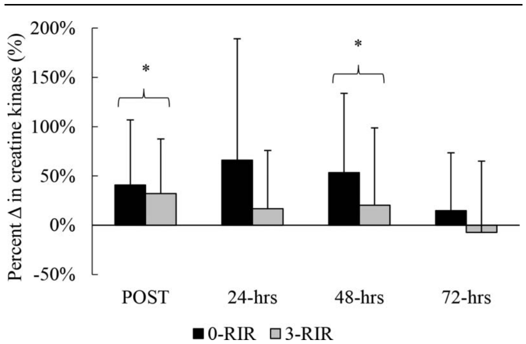


**Figure 4.** Percent changes in creatine kinase over the 72-hour recovery period after each acute bench press condition (mean ± SD). *Significant ($p < 0.05$) difference from pre-exercise concentrations after each condition.

The changes observed with CK concentrations were mirrored by the recovery of barbell kinetics. Barbell velocity and impulse were both diminished after each condition, but no between-condition differences were noted throughout their recovery. Again, this differs from past studies that compared RM with nonfailure sets (13,27,28). The reason for this disagreement may be due to the proximity in which sets were taken to momentary muscular failure. In general, past studies have shown a more rapid recovery (within 24–48 hours) when sets were concluded after half of the expected repetitions were completed (13,27,28). By contrast, all sets in this study were taken to within 3 repetitions of failure and, thus, could be speculated to have incorporated more "stimulating repetitions" for an 8–10 RM load (3). The disagreement may also be related to the specific measures used to monitor performance. Past studies have used countermovement jump, barbell kinetic assessments, or both to monitor fatigue and recovery (13,27,28). Because this study did not involve lower-body exercise, only bench press kinetics were examined. However, past studies observed recovery advantages for nonfailure training more clearly from changes in countermovement jump performance than those seen from barbell velocity (13,27,28). Despite their strong relationship, some have suggested that countermovement jump performance may be more suitable than barbell kinetics for monitoring neuromuscular fatigue (12,32). In hindsight, it is possible that adding a ballistic upper-body exercise (e.g., clapping push-up, bench press throw) to testing would have provided a more comprehensive assessment of recovery.

In this crossover study, resistance-trained men completed 5 sets of bench press at an 80% 1RM load using 2 different repetitions schemes. Both conditions produced comparable amounts of damage and their recovery was the same over a

72-hour period. However, progressive declines in repetitions and work completed, as well as average concentric barbell velocity, were seen across sets taken to momentary muscular failure. By contrast, when subjects halted sets after sensing they were approximately within 3 repetitions of failure, overall barbell velocity was greater, completed repetitions and work were more consistent across sets, and perceived effort was less. These advantages are of primary interest when considering the value of either strategy over the course of training. The data suggest that the 3-RIR strategy better positioned the subjects to continue effort, had more sets, exercises, or training sessions been prescribed. This study adds to an extremely limited body of evidence comparing the utility of the RIR strategy with RM sets (2) and builds on those that compared failure and nonfailure sets (13,27,28,33). Although past and present data collectively suggest that nonfailure sets enable comparable work at lower perceived effort compared with RM sets, the RIR strategy may be incorporated into training in a variety of ways. How these variations compare with each other, as well as other strategies (e.g., percentage-based loading, velocity-based prescription, and RM sets), in both experienced and inexperienced trainees, is still unclear. More comprehensive assessments of the strategy's effect on fatigue, damage, and recovery are also warranted.

## Practical Applications

Most targeted fitness goals are dependent on, among other things, the quality of effort put forth during training. The acute fatigue produced during exercise and that which is accumulated over the course of training can negatively affect effort. Although fatigue is often believed of as a catalyst for adaptation, too much can be detrimental. To this end, several strategies exist to manage fatigue. The results of this study support the use of RIR prescription as one such strategy for managing fatigue in resistance-trained men. During an acute bout of bench press at 80% 1RM load, using the 3-RIR strategy with one final set to failure produced the same amount of work as performing all sets to failure. However, perceived effort was less when conserving repetitions, and this allowed for greater average barbell velocity compared with completing all sets to momentary muscular failure. Based on the trajectory of repetitions, barbell velocity, and perceived effort across each set, it is reasonable to assume that these could be better sustained during the 3-RIR condition, had more sets, and exercises been required. Furthermore, the damage sustained from the bout and subjects' recovery was comparable between conditions and complete within 72 hours. Experienced trainees may consider using the RIR strategy to better sustain effort while still completing the same amount of work as they would using more difficult, RM sets.

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