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THE EFFECT OF RELATIVE LOAD ON BARBELL VELOCITY AND PERCEIVED EXERTION WHEN A 25% VELOCITY LOSS THRESHOLD IS APPLIED TO SETS OF BENCH PRESS

Zachary A. Mang[1,2], Jason R. Beam[3] *, Eric D. Vigil[3], and Adam H. Martinez[3]

[1] Albuquerque Baseball Academy, Strength & Conditioning Program, Albuquerque, NM, USA
[2] University of New Mexico, Department of Health, Exercise, and Sports Sciences, Albuquerque, NM, USA
[3] Los Alamos National Laboratory, Occupational Health, Los Alamos, NM, USA

*Corresponding author: jrbeam@lanl.gov

ABSTRACT

This study's purpose was to assess the effect of relative intensity on perceived exertion and barbell velocity during sets of bench press performed to a velocity loss (VL) threshold of > 25%. Twenty recreationally trained subjects (18-40 yrs.) completed five sets of bench press under three conditions: ascending pyramid, descending pyramid, and constant load. Sets were performed until VL of >25% was achieved and mean/peak velocity of every repetition was recorded. Rating of perceived exertion/repetitions in reserve (RPE/RIR) for each set was measured. This study provides data analyses in which sets performed with 65-70-75-80-85% 1-RM were consolidated. Data revealed significant main effects for repetition volume, barbell velocity (mean, peak, start, and end), measured VL, and RPE/RIR ($p \leq 0.05$). Post-hoc comparisons indicated that repetition volume, barbell velocity (mean, peak, start, and end) significantly decreased as relative intensity increased ($p \leq 0.05$). Measured VL and RPE/RIR significantly increased as relative intensity increased ($p \leq 0.05$). Several significant relationships were observed between relative intensity, relative strength ratio, repetitions completed, measurements of barbell velocity, and RPE/RIR ($p \leq 0.05$). In conclusion, relative intensity influences several aspects of barbell velocity and RPE/RIR. As relative intensity increased RPE/RIR and VL increased incrementally despite the application of a fixed VL threshold.

Keywords: momentary failure; set end point; fatigue; repetitions in reserve

INTRODUCTION

Resistance exercise (RE) is a training modality that is reported to increase muscular endurance, hypertrophy, power, and strength (1). From a clinical perspective, it has been shown that RE improves markers of cardiovascular and metabolic health (2), which culminates as reduced risk for all-cause mortality (3). Thus, RE confers performance and health effects that can benefit a variety of populations. When prescribing an RE program, fitness professionals must consider several training variables that include exercise selection, frequency, volume, tempo, rest intervals, range of motion, external load, and set end point (4). The latter two will be the focus of this manuscript.

External load, which is used synonymously with relative intensity, refers to the amount of weight that is lifted for a given set of RE (5). There are several methods for determining external load including percent of one-repetition maximum (%1-RM), repetition maximum (RM), and velocity-based training (6,7). Of note, the latter technique applies velocity zones and load-velocity relationships to provide individualized external loads that can correspond to %1-RM (8) or an RM (9). Regardless of the method applied, external load is a critical determinant of long-term adaptations (10,11). For instance, skeletal muscle hypertrophy can be stimulated with external loads that range from ~30-90% 1-RM, which corresponds with ~3-35 repetitions per set (4). Muscular strength also increases with a variety of loading schemes (12), but higher relative intensities (>65% 1-RM) are typically more effective than lower relative intensities (<65% 1-RM) (5). Therefore, fitness professionals can undulate external loads within a training session (13) or training program (14) to target a variety of performance outcomes.

Set end point, defined as proximity to momentary failure (5), generally determines the fatigue incurred during sets of RE. Momentary failure, which is sometimes referred to as concentric failure, has been described as the point at which a lifter cannot complete the concentric phase of a repetition without using improper form (15). While momentary failure is clear to define, set end points that fall short of momentary failure are more ambiguous. For example, studies in the proximity-to-failure literature include several terms with varying definitions such as non-failure, set failure, volitional failure, and volitional interruption (16). Others have highlighted that even when momentary failure is clearly defined and implemented, it remains impossible to guarantee that a lifter achieves this level of effort during a given set of RE (17). Because proximity to momentary failure influences long-term adaptations to RE, such as skeletal muscle hypertrophy and strength (5,15-17), it is necessary for researchers to develop methods that objectively measure set end point.

To address this specific issue, velocity loss (VL) thresholds have emerged as a strategy to quantify and control set end point (18-25). As described by Weakley et al. (25), when VL thresholds are used, RE sets are terminated at a pre-defined concentric velocity. For example, if a VL of 20% is applied, and the fastest repetition of a set was 0.8 $m \cdot s^{-1}$, that specific set would be terminated when the lifter performs a repetition that is < 0.64 $m \cdot s^{-1}$. In principle, higher VL indicates greater fatigue and closer proximity to momentary failure (18-25), which has short-term and long-term consequences. For instance, acute data have revealed a dose-response relationship between VL (30 > 20 > 10%) and blood lactate concentration, mechanical fatigue, and rating of perceived exertion (RPE) (25). When repeated over the course of weeks, several studies have suggested that lower VL (0-25%) is superior for power and strength development, while higher VL (>25%) stimulates significantly more skeletal muscle hypertrophy (20-22). Therefore, practitioners can manipulate VL to manage fatigue and target specific adaptations.

Perhaps the biggest limitation of training with VL thresholds is the requirement of a linear velocity transducer that measures concentric velocity. In the absence of using advanced technology to monitor set end point, practical alternatives have emerged such as the RPE scale that measures repetitions in reserve (RIR) (26-31). When using this scale, a lifter will provide an RPE value that corresponds with an RIR value (31). For example, an RPE of '8' indicates that the lifter had 2 RIR, meaning that they were approximately 2 repetitions shy of momentary failure (31). Most RPE/RIR research follows a similar study design in which subjects will perform sets to momentary failure, or other set end points, while approximating their RPE/RIR at certain times during the set (26-31). Velocity loss is often measured during these sets to allow for the identification of RPE/RIR values that correspond with specific VL measurements (26-31). This information is important for fitness professionals, but several gaps in the literature remain.

Specifically, in lieu of performing sets to momentary failure, we are only aware of one study that has fixed VL thresholds (20 vs. 40%) while analyzing the effect of performing RE with different relative intensities (60 vs. 80% 1-RM) (32). However, the study by Pareja-Blanco et al. (32) was solely focused on performance decrements (e.g., sprint speed) in the post-exercise period, and they did not report barbell velocity metrics or RPE/RIR within the actual session. These data may be important considering the correlation between RPE/RIR and velocity (28,29,31), as well as the proposition that RPE/RIR will vary when different relative intensities are used (17). In a similar vein, our research team recently published a study that compared the effect of ascending-pyramid (AP), constant-load (CL), and descending-pyramid (DP) on several barbell velocity metrics and RPE/RIR (33). Although it transcended the primary purpose of the research, we observed that weaker lifters completed repetitions with greater velocities than stronger lifters, and higher RPE/RIR were recorded after sets completed with higher relative intensities despite the application of a uniform VL threshold of 25% (33). The latter finding is particularly interesting, because it may be incorrectly presumed that sets performed to a VL threshold will lead to similar levels of fatigue and perceived effort. These data are intriguing, but it remains unclear if they stemmed from the effect of a specific relative intensity or the specific set configuration during which the relative intensity was applied.

Therefore, the purpose of this study was to assess the combined effects of relative intensities (65-70-75-80-85% 1-RM) and a >25% VL threshold on barbell velocity and RPE/RIR during sets of bench press. To our knowledge, this is the first study to apply a uniform VL threshold to a spectrum of relative intensities during RT sessions. We hypothesized that mean velocity, peak velocity, start velocity, and end velocity would be significantly higher during lighter sets (65-70% 1-RM) compared to heavier sets (80-85% 1-RM) (34). Moreover, we anticipated that RPE/RIR would be significantly lower for lighter sets and would methodically increase with heavier sets (33,35). To further contextualize the data, a secondary purpose of this study was to compare the effect of relative strength on the previously mentioned variables. We hypothesized that mean velocity, peak velocity, start velocity, and end velocity would be significantly higher for those with lower relative strength (33,36) but

RPE/RIR would not differ between groups (33).

METHODS

Study Design

The present study provides secondary data analyses from a randomized, cross-over trial that examined the acute effects of three barbell bench press training sessions: AP (65-70-75-80-85% 1-RM), CL (75-75-75-75-75% 1-RM), and DP (85-80-75-70-65% 1-RM) (33). These sessions were completed in a randomized, counter-balanced fashion and were separated by 3-7 days. The subjects were encouraged to maintain their dietary and exercise habits throughout the study, and they were instructed to avoid vigorous exercise and caffeine consumption for at least 48 h and 4 h, respectively, before each training session. Besides the manner in which relative intensities were performed, every training variable was matched between conditions: volume (5 sets), average relative intensity (75% 1-RM), rest intervals (5 min), and set end point (>25% VL). For the current analyses, data from the CL session were removed, and data from AP and DP training sessions were combined to allow for comparisons between several relative intensities (i.e., 65-85% 1-RM). More specifically, we analyzed the effect of relative intensity on repetition volume, mean velocity (i.e., averaged across all repetitions within a set), peak velocity (i.e., averaged across all repetitions within a set), start velocity, end velocity, measured VL, and RPE/RIR.

Subjects

We recruited a convenience sample within our practical limitations (37), and a total of 20 recreationally-active females (n = 2) and males (n = 18) volunteered for this research (Table 1). To determine if outcomes were dependent upon individual strength levels, subjects were ranked according to their relative strength ratio (RSR; bench press 1-RM ÷ body mass), and the sample was divided into HIGH-RSR (1.17-1.56) and LOW-RSR (0.67-1.16). Each subject self-reported that they were currently satisfying the Physical Activity Guidelines for Americans (38). Pertaining to resistance training, the subjects self-reported that they had completed upper-body exercise ≥ 1 day per week for ≥ 12 months which included consistent performance of barbell bench press. The subjects indicated that they were free of cardiovascular, kidney, liver, metabolic, and viral disease with no orthopedic injuries via completion of a health history questionnaire. Moreover, they were not taking medications or dietary supplements that could affect exercise performance. The subjects were made aware of potential risks and benefits associated with the study, and they subsequently signed an informed consent document that was approved by a Human Subjects Research Review Board at the Los Alamos National Laboratory (Protocol 23-01X).

Procedures

During their first lab visit, subjects had their height measured to the nearest 0.1 cm via a commercially available stadiometer (Road Rod Portable Stadiometer, Hopkins Medical Products, Boston, MA, USA) before having their body composition assessed via bioelectrical impedance (InBody 570, Biospace, La Jolla, CA, USA) in accordance with manufacturer guidelines.

Table 1. Subject characteristics with groups combined (COMB; n = 20) and separated into high relative strength ratio (HIGH-RSR; n = 10) and low relative strength ratio (LOW-RSR; n = 10). Data are displayed as mean ± standard deviation.

Variables	COMB	HIGH-RSR	LOW-RSR	*p*-value	95% CI for MD	Cohen's *d*
Age (y)	30.6 ± 5.2	31.7 ± 5.5	29.4 ± 4.9	0.337	-2.6, 7.2	0.458
RE experience (y)	8.9 ± 5.6	11.9 ± 5.1	5.9 ± 4.4	0.011*	1.5, 10.5	0.529
Height (cm)	177.6 ± 8.4	179.1 ± 6.1	176.0 ± 10.1	0.416	-4.8, 11.2	0.455
BM (kg)	89.9 ± 13.0	87.3 ± 11.3	92.4 ± 14.7	0.402	-17.4, 7.3	0.455
BF%	21.7 ± 9.5	17.3 ± 6.6	26.1 ± 10.2	0.034*	-16.9, 0.7	0.503
1-RM (kg)	104.3 ± 22.2	118.4 ± 19.2	90.2 ± 15.3	0.002*	11.9, 44.5	0.576
1-RM/BM (AU)	1.17 ± 0.24	1.35 ± 0.13	0.99 ± 0.17	<0.001*	0.23, 0.51	0.708

AU = arbitrary units; BM = body mass; BF% = body fat percentage; cm = centimeter CI = confidence intervals; kg = kilogram; MD = mean difference; RE = resistance exercise; y = years; 1-RM = one-repetition maximum for bench press.
*Significant difference between LOW-RSR and HIGH-RSR, $p \leq 0.05$

Following the InBody measurement, subjects performed a one-rep-max (1-RM) bench press test, which we adapted from commonly-used protocols in the literature (19,22,24). Before testing began, the subjects completed the following warm up: 5 minutes on a rowing ergometer, 3-5 minutes of dynamic stretching, and 3-5 minutes of self-selected exercises (e.g., face pulls). This warmup was completed before each subsequent training session. Next, the subjects performed 10 repetitions of bench press with the barbell (20.5 kg) and the researchers verified that proper form was used. From there, successive sets of 3 repetitions were performed with the addition of 9-18 kg per set until the lifter registered an average velocity that was < 0.8 $m \cdot s^{-1}$. Next, successive sets of 2 repetitions were performed with the addition of 4.5-9.0 kg per set until the lifter registered an average velocity that was < 0.5 $m \cdot s^{-1}$. Thereafter, successive sets of 1 repetition were performed with the addition of 1.0-4.5 kg per set until a successful 1-RM was determined. 2-3 min rest intervals were allotted between the 2-3-repetition sets that occurred before the 1-RM attempts, and 3-5 min rest intervals were allotted between each 1-RM attempt. Subjects were instructed to grip the barbell as they typically would and to maintain 5 points of body contact throughout: head, upper back, and buttocks on the bench with both feet planted firmly on the floor (11). For repetition tempo, subjects controlled the eccentric phase, paused for ~1 s with the barbell on their chest, and completed the concentric phase as fast as possible (19,22,24). A linear velocity transducer was fixed to the right side of the barbell via velcro strap (Power Analyzer V-620, TENDO Sports Machines, London, UK) to monitor the velocity of each repetition. These instructions, procedures, and measurement tools were used throughout the study.

The 1-RM test was repeated 2-3 days later during their second lab visit (39), and the intraclass correlation coefficient between measurements was 0.99. If 1-RM measurements were not identical, the higher value was used to determine relative intensities.

Sessions of AP, CL, and DP were performed during the subject's third, fourth, and fifth lab visits. Because data from the CL are not included in the present study, only AP and DP sessions will be detailed in this section.

After the previously described warm up, subjects performed a bench-press-specific warm up: 10 repetitions with the barbell followed by 3 repetitions with 35, 45, and 55% 1-RM. Two extra warm-up sets of 1-2 repetitions were performed with 65% and 75% 1-RM before the DP session. Two minutes of rest were allotted between warm-up sets. For the AP session, sets were performed from lowest to highest relative intensity: 65, 70, 75, 80, and 85% 1-RM. In contrast, for the DP session, sets were performed from highest to lowest relative intensity: 85, 80, 75, 70, and 65% 1-RM. Five-minute rest intervals were provided between sets (40), and subjects continued to perform repetitions until they recorded a mean velocity that was >25% slower than the fastest repetition completed during that set (20-22).

Several measurements were taken during the AP and DP sessions. The Power Analyzer V-260 provided the mean and peak velocities for every repetition during working sets. A researcher recorded these values by hand. As described above, each working set was terminated after a VL of >25%, and the precise VL of each working set was calculated via Microsoft Excel as follows:

[Mean velocity of the fastest repetition ($m \cdot s^{-1}$) – mean velocity of the final repetition ($m \cdot s^{-1}$)] ÷ [Mean velocity of the fastest repetition ($m \cdot s^{-1}$)] × 100

The researchers also recorded how many successful repetitions were completed during each set before achieving the >25% VL threshold (i.e., repetition volume). Immediately after the termination of each working set, the subjects were asked to rank their effort by using a chart that relates RPE to an estimation of RIR (i.e., proximity to momentary failure) (28,29,31). For context, the RPE/RIR scale reads as follows: 10 = maximum effort; 9.5 = no further RIR but could increase load; 9 = 1 RIR; 8.5 = 1-2 RIR; 8 = 2 RIR; 7.5 = 2-3 RIR; 7 = 3 RIR; 5-6 = 4-6 RIR; 3-4 = light effort; 1-2 = little to no effort. Subjects were familiarized with the RPE/RIR scale during visits 1 and 2. For every dependent variable, data from AP and DP were analyzed together, meaning that sets with similar relative intensity (e.g., 70% 1-RM) were combined.

Statistical Analyses

Independent samples t-tests were used to detect statistically significant differences between HIGH-RSR and LOW-RSR for demographic, descriptive, and performance variables. The assumption of normality was checked using the Shapiro-Wilk test for all t-tests. If this assumption was violated ($p \leq 0.05$), the Mann-Whitney U test was used to check the level of significance. The assumption of equality of variances was assessed for all independent t-tests using the Levene's test. If this assumption was violated ($p \leq 0.05$), the Welch test was used to check the level of significance.

Mixed-factor 2 (group) x 5 (relative intensity) repeated-measures ANOVAs were used to analyze main effects and interactions for all dependent variables described in the Study Design section of this manuscript. Post hoc comparisons for statistically significant interactions were analyzed using Tukey's HSD test and reported as means ± standard deviation (SD). Post hoc comparisons for statistically significant main effects were analyzed using the Holm-Bonferroni test and reported as means ± SD. The effect sizes for the omnibus tests (η_p^2 and ω^2) and post-hoc tests (Cohen's *d*) were calculated and reported.

For all ANOVAs, the assumption of equality of variances was assessed using Levene's test. If this assumption was violated ($p \leq 0.05$), the Welch test was used to check the level of significance. The assumption of sphericity was checked using the Mauchly's test of sphericity. If this assumption was violated ($p \leq 0.05$), the Greenhouse-Geisser (if $\varepsilon < .75$) or Huynh-Feldt (if $\varepsilon > .75$) correction was applied to check the level of significance.

Relationships between relative intensity and relative strength ratio, barbell velocity (mean, peak, start, and end) per set, velocity loss per set, repetitions completed per set, and RPE/RIR were analyzed using Microsoft Excel (Microsoft 365). An alpha level of 0.05 was used to determine statistical significance for all analyses. Data were analyzed using the statistical package JASP (Version 0.17.2.1, Amsterdam, The Netherlands).

RESULTS

Repetitions and Rating of Perceived Exertion

There was a statistically significant within-subject main effect for repetitions [F (2.652, 100.484) = 125.783, $p < 0.001$, $\eta_p^2 = 0.768$, $\omega^2 = 0.610$] and RPE/RIR [F (1.929, 73.314) = 46.045, $p < 0.001$, $\eta_p^2 = 0.548$, $\omega^2 = 0.370$]. Post hoc comparisons are displayed in Table 2. Figure 1 shows the statistically significant ($p \leq 0.05$) inverse or negative linear relationship ($R^2 = 0.9857$) between the sample mean repetitions for each set and relative intensity. Figure 2 shows the statistically significant ($p \leq 0.05$) positive linear relationship ($R^2 = 0.9962$) between the sample average RPE/RIR for each set and relative intensity.

Mean Velocity and Peak Velocity

There was a statistically significant within-subject main effect for mean velocity [F (2.016, 76.613) = 506.387, $p < 0.001$, $\eta_p^2 = 0.930$, $\omega^2 = 0.739$] and peak velocity [F (2.031, 73.115) = 268.625, $p < 0.001$, $\eta_p^2 = 0.882$, $\omega^2 = 0.537$]. Post hoc comparisons are displayed in Table 2. Figure 3 shows the statistically significant ($p \leq 0.05$) inverse or negative linear relationship between the sample average mean velocity ($R^2 = 0.9981$) and peak velocity ($R^2 = 0.9988$) for each set and relative intensity. Figure 4 shows the statistically significant ($p \leq 0.05$) inverse or negative linear relationship between the average peak velocity of HIGH-RSR ($R^2 = 0.9948$) and average peak velocity of LOW-RSR ($R^2 = 0.9995$) for each set and relative intensity.

Start Velocity, End Velocity, and Velocity Loss

There was a statistically significant within-subject main effect for start velocity [F (1.829, 69.494) = 431.889, $p < 0.001$, $\eta_p^2 = 0.919$, $\omega^2 = 0.733$], end velocity [F (4, 152) = 250.946, $p < 0.001$, $\eta_p^2 = 0.868$, $\omega^2 = 0.674$], and VL [F (2.821, 107.181) = 7.254, $p < 0.001$, $\eta_p^2 = 0.160$, $\omega^2 = 0.105$]. Post hoc comparisons are displayed in Table 2. Figure 2 shows the statistically significant ($p \leq 0.05$) positive linear relationship ($r = 0.9775$) between the sample mean VL for each set and relative intensity. Figure 5 shows the statistically significant ($p \leq 0.05$) inverse or negative linear relationship between the sample average start velocity ($R^2 = 0.9989$) and end velocity ($R^2 = 0.9991$) for each set and relative intensity.

Figure 1. Relationship between relative intensity and the sample average repetitions from Table 2.

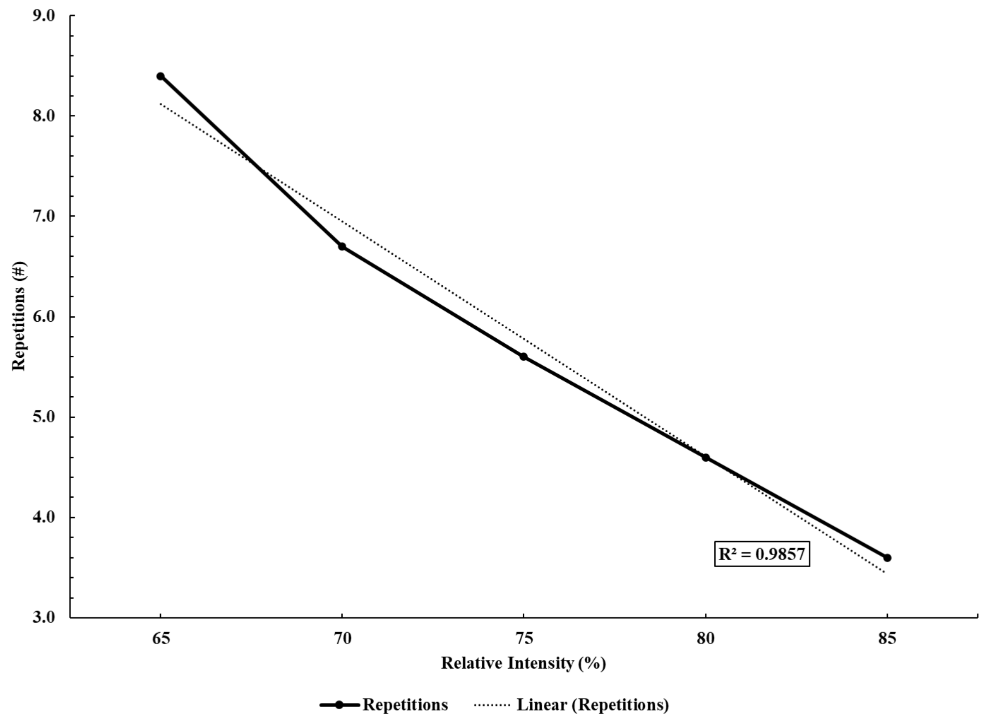

Figure 2. Relationships between relative intensity and the sample average RPE/RIR and velocity loss from Table 2.

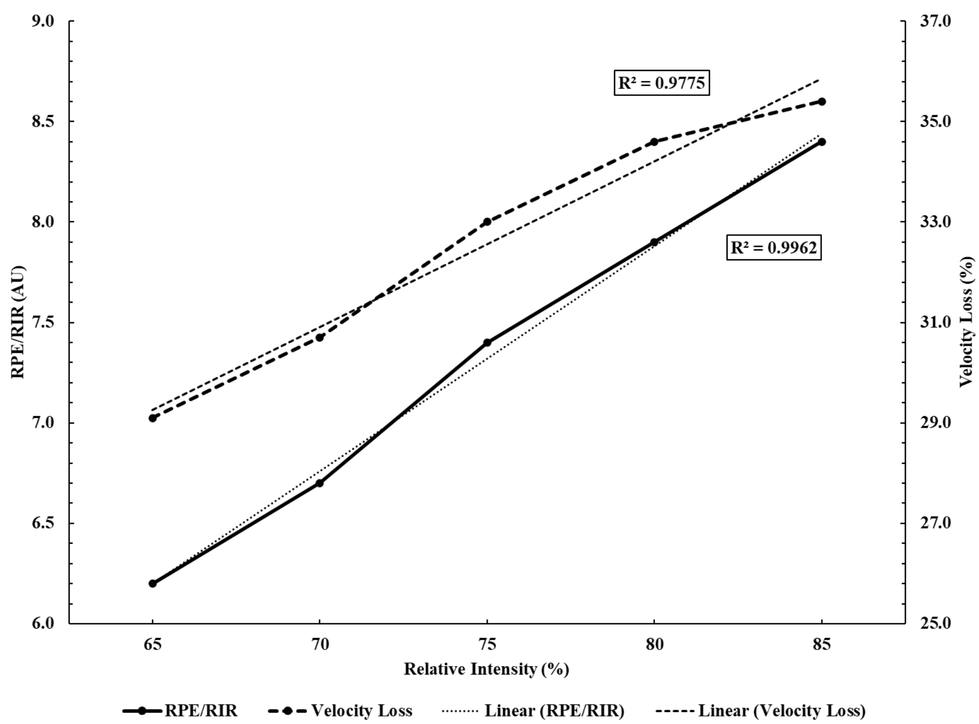

Figure 3. Relationships between relative intensity and the sample average mean velocity and peak velocity from Table 2.

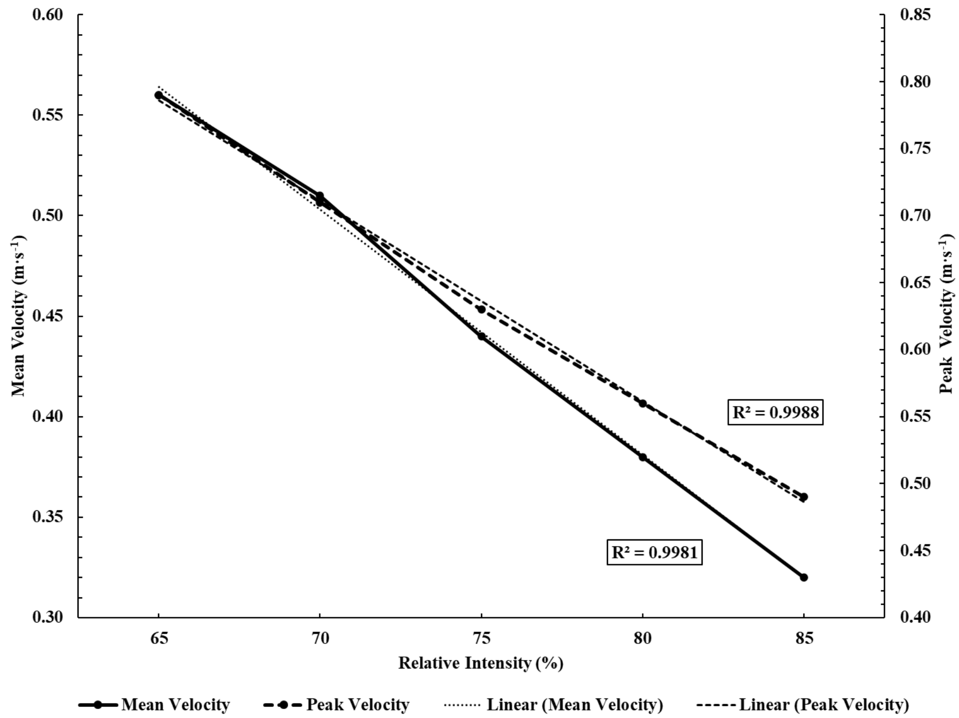

Figure 4. Relationships between relative intensity and the average peak velocity for those with a low relative strength ratio (LOW-RSR) and a high relative strength ration (HIGH-RSR).

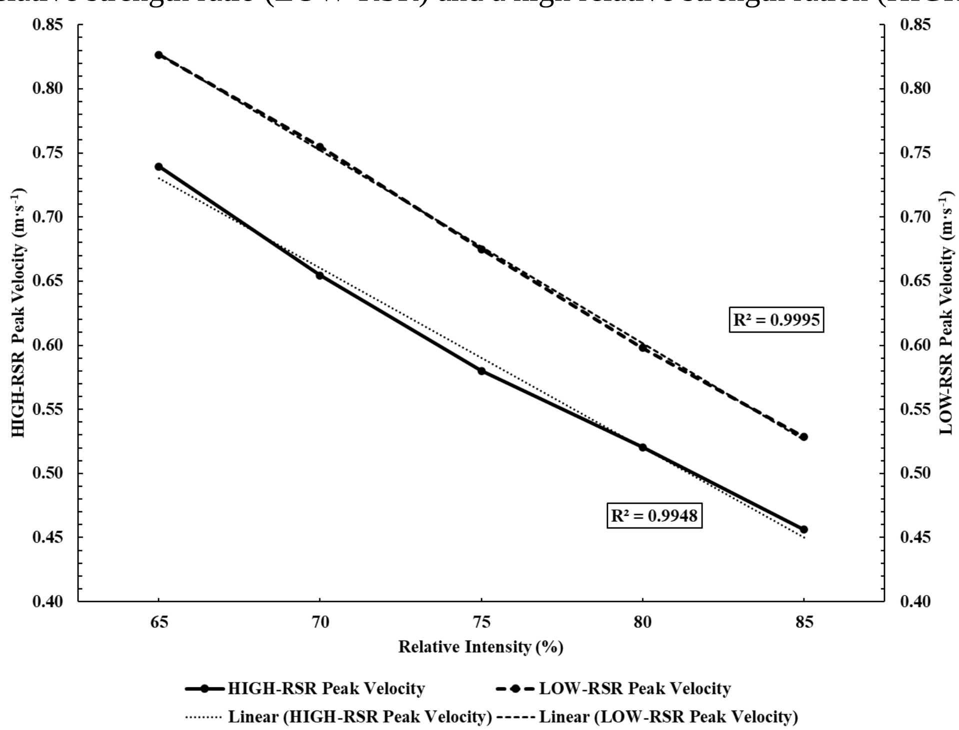

Figure 5. Relationships between relative intensity and the sample average start velocity and end velocity from Table 2.

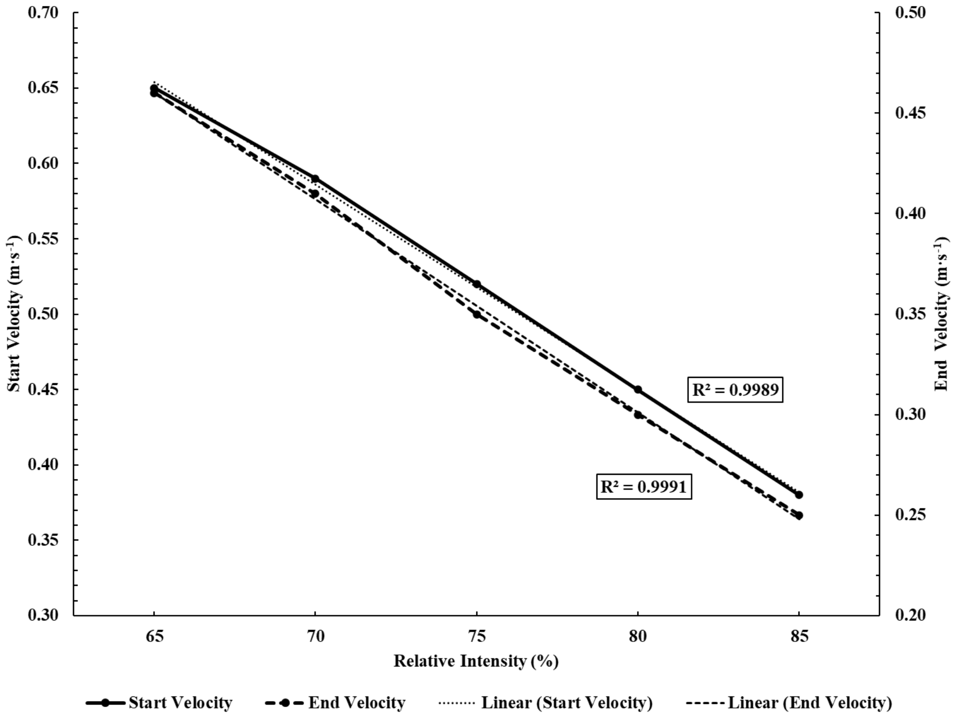

Table 2. The number of successful repetitions completed, RPE/RIR, mean velocity, peak velocity, start velocity, end velocity, and velocity loss with various relative loads (65-85% 1-RM) during sets of bench press. Data are shown as mean ± standard deviation (n = 40).

Intensity (% 1-RM)	Repetitions (AU)[a]	RPE/RIR (AU)	Mean Velocity ($m \cdot s^{-1}$)	Peak Velocity ($m \cdot s^{-1}$)	Start Velocity ($m \cdot s^{-1}$)	End Velocity ($m \cdot s^{-1}$)	Velocity Loss (%)
65%	8.4 ± 1.9	6.2 ± 4.5	0.56 ± 0.06	0.79 ± 0.11	0.65 ± 0.07	0.46 ± 0.05	29.1 ± 2.7
70%	6.7 ± 1.3[b]	6.7 ± 1.2[a]	0.51 ± 0.06[a]	0.71 ± 0.11[a]	0.59 ± 0.06[a]	0.41 ± 0.06[a]	30.7 ± 5.0
75%	5.6 ± 1.2[b,c]	7.4 ± 0.9[a,b]	0.44 ± 0.05[a,b]	0.63 ± 0.11[a,b]	0.52 ± 0.05[a,b]	0.35 ± 0.06[a,b]	33.0 ± 6.4[a]
80%	4.6 ± 1.0[b,c,d]	7.9 ± 0.9[a,b,c]	0.38 ± 0.05[a,b,c]	0.56 ± 0.10[a,b,c]	0.45 ± 0.06[a,b,c]	0.30 ± 0.06[a,b,c]	34.6 ± 7.0[a,b]
85%	3.6 ± 0.8[b,c,d,e]	8.4 ± 0.7[a,b,c,d]	0.32 ± 0.05[a,b,c,d]	0.49 ± 0.09[a,b,c,d]	0.38 ± 0.06[a,b,c,d]	0.25 ± 0.05[a,b,c,d]	35.4 ± 9.5[a,b]

AU = arbitrary units; CI = confidence intervals; MD = mean difference; % 1-RM = percent of one-repetition maximum.

[a] Significant within-group main effect, $p \leq 0.05$
[b] Significantly different than 65%, $p \leq 0.05$
[c] Significantly different than 70%, $p \leq 0.05$
[d] Significantly different than 75%, $p \leq 0.05$
[e] Significantly different than 80%, $p \leq 0.05$

DISCUSSION

Velocity loss thresholds and RPE/RIR have emerged as strategies to quantify set end point during RE sessions. However, the combined effect of relative intensity (65-85%) and a fixed VL threshold (>25%) on RPE/RIR have not been reported in the literature. In this study, when the VL threshold was fixed at >25%, repetition volume, mean velocity, peak velocity, start velocity, and end velocity gradually decreased as relative intensity increased. Contrarily, RPE/RIR and VL gradually increased as relative intensity increased. When relative strength was considered, besides 1-RM (HIGH-RSR > LOW-RSR) and peak velocity (LOW-RSR > HIGH-RSR), no significant differences were observed between groups. These outcomes can better inform practitioners who use the RPE/RIR chart to monitor proximity to momentary failure while using a variety of relative intensities with their clients.

It was expected that repetition volume and barbell velocity would be significantly lower at higher relative intensities, and vice versa. These hypotheses are supported by the data in Figure 1 and Table 2. The observed outcomes reflect the well-known inverse relationship between relative intensity and repetition performance (42) in addition to the force-velocity curve (34). In other words, before surpassing the 25% VL threshold, lighter relative loads were lifted for more repetitions, and with greater velocity, than heavier relative loads. Pertaining to the role of relative strength, the results indicate that those with LOW-RSR registered higher peak velocities than their HIGH-RSR counterparts (Figure 4). This outcome echoes previous research where 'weak' lifters produced higher barbell velocity than 'strong' lifters during sets of bench press with 30-80% 1-RM (36) and 65-85% 1-RM (33). Therefore, the absolute external load lifted during a set of barbell bench press may influence barbell speed more than relative intensity. For example, when relative intensity is matched (e.g., 75% 1-RM) a stronger lifter (e.g., 1-RM = 90 kg performing the set with 68 kg) would have lower barbell speed than a weaker lifter (e.g., 1-RM = 68 kg performing the set with 51 kg). Alternatively, the HIGH-RSR lifters in our study managed to perform more repetitions at slower velocities above the VL threshold for any given set, which ultimately diminished the average peak velocity recorded for these sets. Future research can determine the fidelity of these speculative explanations.

In support of our hypothesis, RPE/RIR incrementally increased with relative intensity. Previous investigations have concluded that when sets are performed to momentary failure, lower relative intensity (25-30 RM) resulted in higher session-RPE than higher relative intensities (8-12 RM) (43). However, when sets are completed shy of momentary failure, others have reported that RPE is significantly greater when higher relative intensities are used (5 reps with 90% 1-RM vs. 15 reps with 30% 1-RM) (35). The current data support the latter finding and suggest that when set end point is controlled with a fixed VL threshold, RPE/RIR is higher when higher relative intensities are used. This may be explained by proximity to momentary failure. For example, because start velocities were significantly lower during the 80-85% 1-RM sets (0.38-0.45 $m \cdot s^{-1}$), the 25% VL threshold resulted in slower end velocities (0.25-0.30 $m \cdot s^{-1}$) that are closer to those associated with momentary failure during bench press (0.12-0.19 $m \cdot s^{-1}$) (26). In short, perceived exertion was higher when higher relative intensities were used, which is likely explained by the previously established inverse relationship between barbell velocity and RPE/RIR (28,29,31). This suggests that fatigue is not uniform for a given

VL threshold when different relative intensities are used.

The finding that measured VL was greater with higher relative intensities was unanticipated and is worthy of further discussion. This suggests that VL between successive repetitions is not uniform across relative loads, and the slope of VL may be steeper when training with 80-85% 1-RM compared to 65-70% 1-RM. Let us consider hypothetical examples to illustrate this point. For instance, if a subject is lifting with an 85% 1-RM load, and their 25% VL threshold is 0.35 $m \cdot s^{-1}$, the third repetition of the set may be 0.38 $m \cdot s^{-1}$ (above the threshold), but the fourth repetition may be 0.28 $m \cdot s^{-1}$ (well below the threshold). On the other hand, when lifting with a 65% 1-RM load, the same subject's 25% VL threshold may be 0.50 $m \cdot s^{-1}$, and the seventh repetition of the set may be 0.52 $m \cdot s^{-1}$ (above the threshold). However, because of a flatter VL slope (Figure 2), the eighth repetition that terminates the set may be performed at 0.49 $m \cdot s^{-1}$ (just below the threshold). The current data and associated hypotheticals support previous research that retroactively compared the percentage of performed repetitions at various VL when sets were completed to momentary failure (19). Specifically, at higher relative intensities (75-85% 1-RM), the percentage of total repetitions performed was greater for any given magnitude of VL when compared to lower relative intensities (50-70% 1-RM) (19). Taken together, the data reflect that rep-to-rep VL is greater when higher relative intensities are lifted.

In the absence of measuring barbell velocity, coaches and athletes may use the RPE/RIR scale to monitor set end point and/or proximity to momentary failure. The current data indicate that when VL is fixed at >25%, lifters will report higher RPE/RIR when heavier relative loads are used, and absolute VL will be higher under these circumstances. The latter point is critical, because when relative intensity was fixed (60 or 80% 1-RM) greater magnitudes of VL (40 vs. 20%) led to longer lasting mechanical fatigue as reflected by reduced performance in sprint speed and vertical jump height (32). The data presented in this study will allow practitioners to make more precise assessments for proximity to momentary failure when VL cannot be measured, and a variety of relative intensities are used. For example, when using lighter relative loads (65-70% 1-RM), if an athlete is required to terminate a set at an RPE/RIR of 8, this will likely be accomplished at a higher VL than an RPE/RIR of 8 when heavier relative loads are used (80-85% 1-RM). This information is beneficial considering that long-term adaptations to RE, such as hypertrophy, power, and strength, may be influenced by specific magnitudes of VL (17,18,20-22). It is advisable for practitioners to use a combination of VL and RPE/RIR when monitoring set end point and fatigue. As a hypothetical, if a strength coach has programmed a specific VL (e.g., 25%) with the intent to elicit a particular RPE/RIR (e.g., 7), monitoring both during/after each set can allow for set-to-set load adjustments as a form of autoregulation (44). Thus, if the RPE/RIR is higher or lower than expected, load for the next set can be decreased or increased, respectively.

For limitations, it should be noted that these data were collected on previously trained young subjects who lifted moderate-heavy loads (65-85% 1-RM) to a VL of 25% during sets of bench press. Thus, the outcomes should be cautiously generalized to other populations, relative intensities, VL thresholds, and exercises. In addition, the current outcomes assume that the linear velocity transducer provided accurate information (45) and that subjects completed every repetition with maximal intent. Indeed, it is possible that if a repetition was not completed with maximal intent, or if the subject experienced a momentary lapse in proper form, they may have registered a slower velocity that terminated a set despite not accurately reflecting their fatigue level. Also, despite being an effective tool for practical application, lifters generally have a difficult time approximating their true RPE/RIR, regardless of their training status (46). However, because each subject served as their own control, it is likely that their individual ability to approximate RPE/RIR was consistent for every experimental condition. Last, the subjects were thoroughly educated about the difficulty of the training session and to maintain their typical eating and hydration status before each lab visit. We relied on them to follow these instructions and did not assess their pre-exercise fueling, which may influence acute RE performance (47).

CONCLUSIONS

When a VL threshold of >25% is applied to sets of bench press, barbell velocity and perceived exertion vary across loading ranges that correspond with 65-85% 1-RM. Unsurprisingly, and in line with an abundance of RE research, repetition volume and barbell velocity decreased as relative intensity increased. However, an interesting trend was observed between perceived exertion and relative intensity as values for RPE/RIR incrementally increased as heavier external loads were lifted. Although speculative, this relationship may be explained by the fact that sets with higher relative intensity were terminated at end velocities that were closer to those typically observed at momentary failure for the bench press. Regardless, this finding bears practical importance because VL influences long-term adaptations to RT. For example, generally, greater magnitudes of VL are more beneficial for hypertrophy while lower magnitudes of VL are more beneficial for power and strength. Future research can vary relative intensities (e.g., 60-80% 1-RM) and VL thresholds (e.g., 10-50%) to assess their concurrent effects on RPE/RIR. For now, we submit that a fixed VL threshold does not lead to consistent fatigue and perceived exertion when different external loads are used.

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