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The Acute Effect of Ascending-Pyramid, Descending-Pyramid, and Constant-Load Set Configurations on Repetition Performance, Training Volume, and Barbell Velocity During Bench Press Exercise

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ABSTRACT

This study analyzed the effect of ascending pyramid (AP), constant load (CL), and descending pyramid (DP) training on repetition performance, training volume, barbell velocity, mechanical fatigue, and perceptual measurements during bench press exercise. Eighteen well-trained young males (18-40 years) performed AP, CL, and DP in a randomized order. Subjects were ranked according to relative strength ratio (Bench press 1-RM ÷ body mass) and the total sample of 18 males was divided into two groups: group 1 (G1), n = 9, RSR = 1.20-1.56; group 2 (G2), n = 9, RSR = 0.75-1.16. Volume (5 sets), relative intensity (65-85% 1-RM), set end point (25% velocity loss (VL)), and rest intervals (5 min) were matched between conditions. Relative intensity did not change during CL (75% 1-RM), while sets were performed from light-to-heavy during AP (65-70-75-80-85% 1-RM), and heavy-to-light during DP (85-80-75-70-65% 1-RM). Repetition performance, total volume load (TVL), mean and peak velocity, VL, and ratings of perceived exertion (set-RPE) were measured during each session while affect, discomfort, enjoyment, and session-RPE were measured after each session. Mean and peak velocity with 45% 1-RM were assessed before, 5-min after, and 10-min after each session. Data indicated that peak velocity and set-RPE were significantly lower during DP ($p \leq 0.05$) while no differences were detected between AP and CL. Session x set interactions ($p \leq 0.05$) were observed for repetition performance, mean velocity, peak velocity, VL, and set-RPE, but differences were likely influenced by fluctuating relative intensities during AP and DP. Data also revealed that lifters from G2 executed their repetitions with greater mean and peak velocities than G1 ($p \leq 0.05$), suggesting that relative strength influences barbell velocity. In conclusion, AP, CL, and DP are viable options for training sessions, but the latter may negatively affect peak velocity.

Keywords: Training techniques; resistance training performance; velocity loss threshold

INTRODUCTION

Resistance training (RT) is reported to stimulate several neuromuscular adaptations such as increased local muscular endurance, skeletal muscle hypertrophy, strength, and power (5, 18, 27, 43, 44). External load, which is often used synonymously with relative intensity, is among the most researched and manipulated RT variables (5, 35, 44). Recent reviews have concluded that significant skeletal muscle hypertrophy occurs along a spectrum of relative intensities (~30-90% of one-repetition maximum; 1-RM) when sets are performed close to momentary failure (5, 44). Muscular strength and endurance can be stimulated with a variety of relative intensities, but heavier external loads are typically more efficient for the former, while lighter external loads are typically more efficient for the latter (5, 17, 44). Traditionally, lifters keep the relative intensity constant for each set of an exercise for a given training session (2, 36, 40). In turn, the relative intensity may be rotated in a daily, weekly, or monthly fashion depending on the type of periodization model being used, or the specific training block that is completed (27).

Alternatively, pyramid training programs involve changing external loads on a set-to-set basis for a given exercise within a training session (4, 26). Several pyramid training programs have been studied in the literature, but most are characterized by working from light-to-heavy, heavy-to-light, or a combination of the two (4, 26). Ascending pyramid training (AP), which involves working from light-to-heavy, is arguably the most-commonly utilized training program in this area of research (2, 7, 8, 12, 29, 36). On the other hand, descending pyramid training (DP), which is often used synonymously with reverse pyramid training, involves working from heavy-to-light (11, 21, 40). Surprisingly, few studies have compared AP to DP (21), and the majority have involved rehabilitation training programs known as DeLorme and Oxford techniques (10, 14, 30, 33).

Thomas DeLorme developed the first AP program during which a light set (10 repetitions with 50% of 10-RM) was performed before a moderate set (10 repetitions with 75% of 10-RM), which was followed by a final, heavy set (10 repetitions with 100% of 10-RM) (14, 26). This AP program, which was aptly named the DeLorme method, allowed the lifter to perform two additional warm-up sets before completing one heavier set to failure (14, 26). Other researchers claimed that it may be safer to perform the heaviest set earlier in the training session to avoid the residual fatigue from preceding sets (14, 26). Thus, the Oxford method, which is an inversion of the DeLorme method, became the first widely practiced DP program (14, 26). Acute studies have indicated that both programs cause similar muscle damage (10, 33) and activation (30), while longitudinal data have demonstrated that both programs similarly increase 1-RM and 10-RM for a variety of total-body exercises (10, 14, 33). For context, the DeLorme and Oxford training methods were designed as post-World War II rehabilitation programs and most of the research has been conducted on subjects with minimal experience with RT.

Several studies have investigated the acute effects of pyramid training systems on hormonal response, metabolic stress, muscle activation, muscle damage, perceived exertion, and training volume (2, 7, 8, 11, 29, 30, 40). Aside from the DeLorme and Oxford studies, the acute effects of AP and DP have not been compared under more ecologically-valid conditions utilizing participants who are experienced and well-trained lifters. Moreover, the current literature is bereft of an acute study that has compared AP and DP to constant load (CL) training, during which the same relative intensity is used for every set. Although not specific to pyramid training, the acute effects of various set configurations have been studied, and researchers have consistently reported that volume completed with moderate-load, hypertrophy-style training (3-4 sets to failure with 60-70% 1-RM) is enhanced when preceded by heavier, priming sets (1-3 sets of 2-3 reps with 85-90% 1-RM) (1, 9, 24). If this phenomenon is consistent, it may logically follow that acute neuromuscular performance is better during DP compared to AP and CL due to a post-activation potentiation (PAP) effect (30, 45).

Therefore, the primary purpose of this study was to compare the acute effects of CL, AP, and DP on repetition performance, total volume load (TVL), and barbell velocity in a population of well-trained lifters. We hypothesized that repetition performance, TVL, mean velocity, and peak velocity would not differ between AP and CL, but these variables would all be significantly higher during DP. The secondary purpose of this study was to compare the acute effects of CL, AP, and DP on affect, discomfort, enjoyment, and ratings of perceived exertion (RPE). We hypothesized that no significant differences would be detected between the experimental conditions for any perceptual variable. To further contextualize the data, we compared the previously listed variables between subjects based on their relative strength ratio. Besides external load and TVL, which would be higher for the stronger subjects, we did not expect to find differences between groups.

METHODS

Experimental Approach to the Problem

The present study used a randomized, cross-over design to examine the acute performance and perceptual effects of three training sessions during sets of bench press: CL (75-75-75-75-75% 1-RM), AP (65-70-75-80-85% 1-RM), and DP (85-80-75-70-65% 1-RM). Several training variables were matched between conditions including set volume (5 sets), average relative intensity (75% 1-RM), rest intervals (5 min), and set end point (25% velocity loss; VL). These protocols were completed in a randomized, counter-balanced fashion and were separated by a period of 3-7 days. Each subject performed their sessions at a similar time of day to avoid the effect of circadian rhythm on diurnal hormones and exercise performance. The average velocity and peak velocity were measured for every repetition via a linear velocity transducer (Power Analyzer V-620, TENDO Sports Machines, London, UK). Repetitions completed and TVL were also recorded for each training session. To quantify mechanical fatigue, the subjects completed 3 maximal-intent repetitions with 45% 1-RM before (i.e., during the warmup), 5-min after, and 10-min after each training session. Subjects reported their RPE immediately after each working set and they were asked to rank their affect, discomfort, enjoyment, and session-RPE 15 min after each training session. The subjects were encouraged to maintain their dietary and physical activity 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. Diet was not controlled, but we informed the subjects to eat and hydrate as they typically would to prepare for a high-volume, high-intensity RT session.

Subjects

18 healthy, resistance-trained males from a corporate wellness center volunteered for participation. We recruited as many subjects as possible within practical limitations (25, 39). These subjects were ranked according to relative strength ratio (RSR; bench press 1-RM ÷ body mass) and the total sample of 18 males was further divided into two groups: group 1 (G1), n = 9, RSR = 1.20-1.56; group 2 (G2), n = 9, RSR = 0.75-1.16. Each subject self-reported participating in ≥ 75 min of vigorous intensity or ≥ 150 min of moderate intensity cardiovascular exercise each week, in addition to ≥ 2 days of RT (31). The subjects also self-reported that they had performed upper-body RT ≥ 1 day/week for ≥ 12 months and were currently including barbell bench press in their program. All anthropometric, demographic, and training-status information is displayed in Table 1. The subjects indicated that they were free of cardiovascular, kidney, liver, metabolic, and viral disease with no orthopedic injuries via health history questionnaire. They were not taking medications or dietary supplements that could affect exercise performance. Before volunteering, the subjects were made aware of all potential risks and benefits associated with the study, and they subsequently signed an informed consent document. This study was approved by the Los Alamos National Laboratory Human Subjects Research Review Board (Protocol 23-01X) in accordance with the Declaration of Helsinki.

Procedures

Anthropometrics and Body Composition (Visit 1)

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). Prior to body composition assessment, subjects refrained from alcohol and caffeine for 24 hrs., abstained from exercise and eating for at least 3 hrs., and ensured proper hydration the day before testing. They also used the restroom and stood for 5 minutes before the assessment. Subjects stood barefoot on the bioelectrical impedance device with the soles of their feet on the electrodes while grasping the handles of the device so their fingers and thumb contacted the electrodes. Next, they stood for ~15 seconds with their arms fully extended and abducted ~30° from their trunk while the measurement was taken.

1-RM Strength Test (Visits 1 and 2)

Before beginning the 1-RM test (32, 38, 41, 42), subjects performed the following standardized warm-up: 5 min of rowing on a rowing ergometer followed by cat-cow flow, thoracic rotations, dynamic down dogs, and pushups (8-10 repetitions each). After the standardized warm-up, subjects were permitted 3-5 min to perform any exercise that they would typically do before a bench press training session. This warm-up was repeated during subsequent testing sessions. Next, subjects performed 10 repetitions of bench press with the barbell (20.5 kg) and the researchers verified that proper form was used. Successive sets of 3 repetitions were then performed with the addition of 9-18 kg per set until the lifter registered an average velocity that was < 0.8m·s^{-1}. From there, successive sets of 2 repetitions were performed with the addition of 4.5-9 kg per set until the lifter registered an average velocity that was < 0.5 m·s^{-1}. Thereafter, successive sets of 1 repetition were performed with the addition of 1-4.5 kg per set until a successful 1-RM was determined. The 1-RM was determined within 5 attempts, and the average sets completed during the test was 11.0 ± 1.3.

Subjects rested 2-3 min between the sets of 2-3 repetitions and 3-5 min between the 1-RM attempts. For each repetition, subjects were instructed to grip the barbell as they would during their usual training sessions 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 (43). Lifters controlled the eccentric phase of motion, paused for ~1 s with the barbell on their chest, and performed the concentric phase of motion as fast as possible following a “go” command from a researcher (41, 42). Velocity was monitored with the linear velocity transducer (Power Analyzer V-620, TENDO Sports Machines, London, UK) that was fixed to the right side of the barbell via a velcro strap. The same instructions, procedures, and measurement tools were used for every training session. The 1-RM test was repeated 2-3 days later and the intraclass correlation coefficient (ICC) between measurements was 0.99 (16). If the 1-RM measurements were not identical, the higher value was used to determine the relative intensities for the CL, AP, and DP sessions.

Resistance Training Sessions (Visits 3-5)

Following the above-mentioned 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. Subjects were encouraged to perform these warm-up sets with maximal intent, especially because the 45% 1-RM set was used to help quantify mechanical fatigue (38, 41). One extra warm-up set of 1-2 repetitions was performed with 65% 1-RM before the CL session and two extra warm-up sets of 1-2 repetitions were performed with 65% and 75% 1-RM before the DP session. These sets were added to provide an incremental ascension to working sets that began with higher relative loads. Two minutes of rest were allotted between each warm-up set.

During the CL session, the same relative intensity was used for each set: 75% 1-RM. For the AP session, sets were performed from lowest to highest relative intensity: 65, 70, 75, 80, and 85% 1-RM. 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 (19), 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, 34).

To assess for mechanical fatigue, subjects performed 3 maximal-intent repetitions with 45% 1-RM 5 and 10 minutes after the session was completed. This specific relative intensity was chosen because it corresponds with ~1.0 m·s^{-1}, a velocity has been used to assess mechanical fatigue in previous research (38, 41).

Performance Measurements

Total volume load. The TVL (sets x repetitions x external load) was recorded and calculated for each training session.

Mean and peak velocity. Mean and peak velocity was recorded for every repetition during each working set. A researcher recorded these values by hand.

Velocity Loss. Each working set was terminated after a VL of 25%, and the VL of each working set was calculated via spreadsheet (Microsoft Excel, Microsoft Office, 365, Microsoft, Washington, USA) as follows:

[(Velocity of the fastest repetition (m·s^{-1}) – velocity of the final repetition (m·s^{-1})) ÷ velocity of the fastest repetition (m·s^{-1})] x 100

Mechanical fatigue. The average of the mean and peak velocities from the 3 repetitions completed at each time point (pre, 5-min post, and 10-min post) was calculated and compared between conditions (38, 41). We allowed 5 and 10 min of recovery to quantify the fatigue incurred during the entire session instead of the final set within that session. The ICCs for mean and peak velocity were 0.84 and 0.83, respectively.

Perceptual Measurements

Set-RPE. Immediately after the termination of each working set, the subjects ranked their effort on a 1-10 scale that relates RPE to an estimation of repetitions in reserve (i.e., proximity to momentary failure; RIR) (28, 48).

Enjoyment. Subjects filled out an 18-item Physical Activity Enjoyment Scale (PACES). Negatively worded PACES items were reverse-scored and the scores from each question were summed to provide a total score out of 126 (higher scores indicate more enjoyment) (3).

Session-RPE and Discomfort. Subjects used an RPE scale to rank their effort from 0 (extremely easy) to 10 (extremely hard) for the entire session (32). In addition, they used the discomfort scale to rank their discomfort from 0 (no perceived discomfort) to 10 (maximum perceivable discomfort) (35).

Affect. Subjects were asked to rank their affect/mood on a +5 (very good) to -5 (very bad) scale, which has previously been used during RT sessions (37).

Enjoyment, session-RPE, discomfort, and affect were recorded 15 min after the termination of the final working set of each session. Also, subjects were familiarized with all perceptual scales during visits 1 and 2 before data were collected during visits 3-5.

Statistical Analyses

Independent samples t-tests were used to detect statistically significant differences between G1 and G2 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. The Cohen's *d* effect size (ES) was reported for all t-tests when the assumption of normality was not violated. The rank-biserial correlation was used to report the effect size when the assumption of normality was violated.

Mixed-factor 2 (group) x 3 (session) repeated-measures ANOVAs were used to compare external load, TVL, affect, discomfort, enjoyment, and session-RPE between CL, AP, and DP. Mixed-factor 2 (group) x 3 (session) x 5 (set) repeated-measures ANOVAs were used to compare differences in set-RPE, repetitions per set, mean velocity, peak velocity, and VL. A mixed-factor 2 (group) x 3 (session) x 3 (time) repeated-measures ANOVA was used to compare changes in mean velocity and peak velocity at a load equivalent to 45% 1-RM before and after the training sessions. Post hoc comparisons for statistically significant interactions were analyzed using Tukey's HSD procedure and reported as means ± standard deviation (SD). Evaluation of post hoc comparisons for repetition and velocity data were limited to set-by-set within each session (i.e., Set 1 vs. 2, 3, 4, and 5; Set 2 vs. 3, 4, and 5; Set 3 vs. 4 and 5; and Set 4 vs. 5) and sets completed with same relative intensities between sessions (e.g., Set 1 AP (65% 1-RM) vs. Set 5 DP (65% 1-RM). All within and between-session post hoc comparisons were evaluated for mechanical fatigue, VL, and set-RPE. Statistically significant main effects for were analyzed using post hoc tests with Bonferroni correction for multiple comparisons and reported as marginal means ± SD.

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. The effect sizes for the omnibus tests (main effects and interactions) were reported as η_p^2 and ω^2. Reporting η_p^2 solves the problem relating to population variance overestimation allowing for comparison of the effect of the same variable in different studies. However, statistical bias using η_p^2 is elevated with small sample sizes. Therefore, we also reported ω^2 because our sample size was small ($n < 30$), and ω^2 provides an unbiased effect size measure. The Cohen's *d* effect size was calculated for all pairwise comparisons. 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

Anthropometric, Descriptive, and Baseline Performance Data

Anthropometric, descriptive, and baseline performance data can be viewed in Table 1. There were statistically significant differences between G1 and G2 for 1-RM and relative 1-RM. In the comparative analysis between the groups, G1 reported significantly higher values with large effect sizes in both absolute 1-RM (Δ: 25.5%, ES: 1.65) and relative 1-RM (Δ: 34.0%, ES: 2.79) compared to G2 (Table 1). The range of 1-RM for G1 and G2 was 97.7-143.2 kg and 61.4-106.8 kg, respectively. The range of relative 1-RM for G1 and G2 was 1.20-1.56 and 0.75-1.16, respectively. Although not statistically different, anthropometric measures of body mass (ES: 0.59), body fat percentage (ES: 0.64) and total body fat (ES: 0.70) reported medium effects sizes, with G2 having greater values than G1 on average.

External Load, Repetitions, and Total Volume Load

There was a statistically significant between-subject main effect for external load [F (1, 16) = 10.076, η_p^2 = 0.386, ω^2 = 0.211] and TVL [F (1, 16) = 17.696, η_p^2 = 0.525, ω^2 = 0.329]. External load (Δ: 22.6%, ES: 1.46) and TVL (Δ: 29.9%, ES: 1.67) values for G1 were significantly greater when compared to G2 (Table 2). There was a statistically significant session x set interaction for repetitions set-by-set [F (3.092, 49.466) = 70.632, η_p^2 = 0.815, ω^2 = 0.613]. Post hoc comparisons for set-by-set repetitions are displayed in Figure 1.

Mean Velocity and Peak Velocity

There was a statistically significant session x set interaction [F (3.442, 55.064) = 318.726, η_p^2 = 0.952, ω^2 = 0.768], within-subjects main effect on set [F (4, 64) = 18.437, η_p^2 = 0.535, ω^2 = 0.069], and a between subjects main effect on group [F (1, 16) = 6.601, η_p^2 = 0.292, ω^2 = 0.141] for mean velocity. Post hoc comparisons for the session x set interaction are displayed in Figure 2A. Irrespective of session and set, mean velocity (Δ: 9.3%, ES: 1.00) values for G2 were significantly greater when compared to G1 (Table 2).

There was a statistically significant session x set interaction [F (2.934, 38.139) = 149.979, η_p^2 = 0.919, ω^2 = 0.479], within-subjects main effect on session [F (2, 26) = 8.589, η_p^2 = 0.398, ω^2 = 0.031], within-subjects main effect on set [F (4, 52) = 10.094, η_p^2 = 0.437, ω^2 = 0.025], and a between subjects main effect on group [F (1, 13) = 8.311, η_p^2 = 0.390, ω^2 = 0.207] for peak velocity. Post hoc comparisons for the session x set interaction are displayed in Figure 2B. Irrespective of session and set, peak velocity (Δ: 22.4%, ES: 1.36) values for G2 were significantly greater when compared to G1 (Table 2). Irrespective of set, peak velocity (Δ: 6.5%, ES: 0.43) values for AP were significantly greater when compared to DP (Table 3).

It is noteworthy to mention that the mean velocity at 65 and 70% 1-RM during AP were significantly greater than the mean velocity at 65% and 70% 1-RM during DP (Δ at 65% 1-RM: 9.1%, ES: 1.06; Δ at 70% 1-RM: 8.2%, ES: 0.79) (Figure 2A); however, this did not happen with loads at 75%, 80%, and 85% 1-RM. Similar results were observed with peak velocity at 65 and 70% 1-RM (Δ at 65% 1-RM: 12.0%, ES: 0.99; Δ at 70% 1-RM: 7.2%, ES: 0.74) (Figure 2B).

Velocity Loss

A statistically significant between-subject main effect, within-subject main effect, or group x session interaction was not observed for VL; however, there was a statistically significant session x set interaction for VL [F (8, 128) = 3.871, η_p^2 = 0.195, ω^2 = 0.121]. Post hoc comparisons for VL are displayed in Figure 3. The VL during Set 1 of DP was statistically great-

Table 1. Anthropometric and descriptive data for Group 1 (G1), Group 2 (G2), and with groups combined.

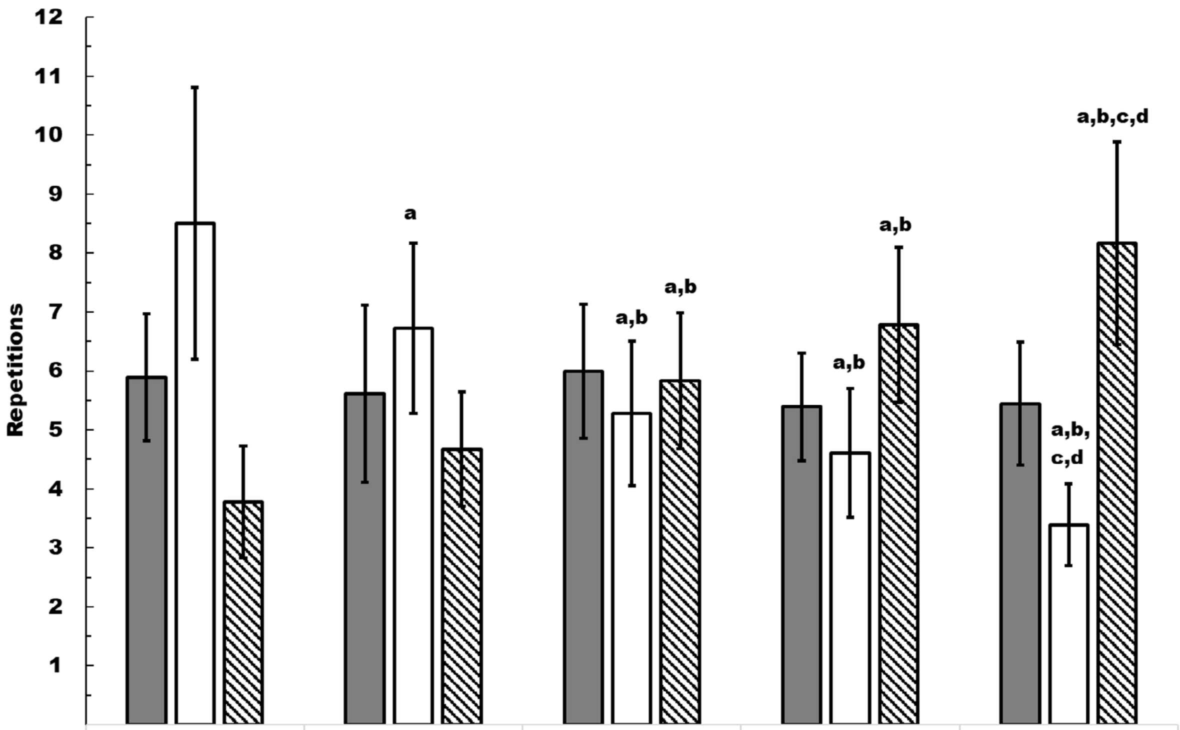
Dependent Variable	G1 (n = 9)	G2 (n = 9)	Group (n = 18)	ES
Height (cm)	178.5 ± 6.6	180.8 ± 3.8	179.6 ± 5.4	0.421
Body Mass (kg)	87.7 ± 11.9	94.7 ± 12.0	91.2 ± 12.1	0.588
Age (yrs.)	31.1 ± 5.5	31.3 ± 4.8	31.2 ± 5.0	0.043
RT History (yrs.)	11.0 ± 4.5	7.6 ± 6.5	9.3 ± 5.7	0.493
Body Fat (%)	17.6 ± 7.0	22.5 ± 8.5	20.1 ± 8.0	0.638
Body Fat (kg)	15.7 ± 7.1	22.2 ± 11.2	18.9 ± 9.7	0.699
Skeletal Muscle Mass (kg)	41.5 ± 6.0	41.6 ± 2.7	41.6 ± 4.5	0.010
1-RM (kg)	120.7 ± 18.8*	96.2 ± 9.4	108.5 ± 19.2	1.649
Mean Velocity at 1-RM ($m \cdot s^{-1}$)	0.10 ± 0.04	0.12 ± 0.03	0.11 ± 0.04	0.432
Relative 1-RM	1.38 ± 0.11*	1.03 ± 0.14	1.20 ± 0.22	2.796

** Indicates significantly greater than G2, p ≤ 0.05; cm = centimeter; kg = kilogram; $m \cdot s^{-1}$ = meters per second; G1 = Group 1; G2 = Group 2; RT = resistance training; Group = Combined data for G1 and G2; ES = Cohen's d effect size. Data are displayed as mean ± standard deviation.*

Table 2. Results for the main effects on group observed when sets and sessions were combined.

Dependent Variable	Group	Mean ± SD	95% CI for Mean Difference Lower	95% CI for Mean Difference Upper	SE	ES
External Load (kg)	1	90.0 ± 14.3	82.2	97.9	3.7	1.46
	2	73.4 ± 7.4*	65.6	81.3	3.7	
TVL (kg)	1	2558.8 ± 402.4	2348.7	2768.8	99.1	1.67
	2	1969.2 ± 270.3*	1759.2	2179.3	99.1	
Mean Velocity (m·s^{-1})	1	0.43 ± 0.05	0.40	0.45	0.01	1.00
	2	0.47 ± 0.04*	0.44	0.50	0.01	
Peak Velocity (m·s^{-1})	1	0.58 ± 0.08	0.51	0.65	0.03	1.36
	2	0.71 ± 0.10*	0.64	0.78	0.03	
Mechanical Fatigue Mean Velocity (m·s^{-1})	1	0.91 ± 0.07	0.87	0.95	0.02	1.09
	2	0.97 ± 0.04*	0.93	1.01	0.02	
Mechanical Fatigue Peak Velocity (m·s^{-1})	1	1.30 ± 0.12	1.23	1.37	0.03	1.48
	2	1.45 ± 0.07*	1.38	1.51	0.03	

** Indicates significantly different than Group 1, $p \leq 0.05$; CI = confidence intervals; kg = kilogram; m·s^{-1} = meters per second; SE = standard error; ES = Cohen's d effect size. Data are displayed as mean ± standard deviation (SD).*



	Set 1	Set 2	Set 3	Set 4	Set 5
CL	5.9	5.6	6.0	5.4	5.4
AP	8.5	6.7	5.3	4.6	3.4
DP	3.8	4.7	5.8	6.8	8.2

Figure 1. The number of repetitions completed during constant load (CL), ascending pyramid (AP), and descending pyramid (DP) training sessions.

Figure 1 Note: Significant post-hoc comparisons are shown above, and data are mean ± standard deviation (n =18). [a] Indicates significantly different than Set 1 within session, $p \leq 0.05$; [b] indicates significantly different than Set 2 within session, $p \leq 0.05$; [c] indicates significantly different than Set 3 within session, $p \leq 0.05$; [d] indicates significantly different than Set 4 within session, $p \leq 0.05$.

Table 3. Results for the main effects on session when sets and groups were combined.

Variable	Session	Mean ± SD	95% CI for Mean Difference Lower	95% CI for Mean Difference Upper	SE	ES CL vs. AP	ES CL vs. DP	ES AP vs. DP
Peak Velocity ($m \cdot s^{-1}$)	CL	0.64 ± 0.09	0.59	0.69	0.02	0.19	0.24	0.43
	AP	0.66 ± 0.09	0.61	0.71	0.02			
	DP	0.62 ± 0.10*	0.57	0.67	0.02			
RPE	CL	7.3 ± 0.9	6.9	7.7	0.2	0.18	0.32	0.50
	AP	7.5 ± 1.0	7.1	7.9	0.2			
	DP	7.0 ± 1.1*	6.6	7.4	0.2			

** Indicates significantly different than AP, $p \leq 0.05$; CL = constant load; AP = ascending pyramid; DP = descending pyramid; CI = confidence intervals; kg = kilogram; $m \cdot s^{-1}$ = meters per second; RPE = rating of perceived exertion; SE = standard error; 1-RM = one-repetition maximum; ES = Cohen's d effect size. Data are displayed as mean ± standard deviation (SD).*

er than Set 5 (Δ: 18.3%, ES: 1.27). Irrespective of group, the VL of Set 1 during DP was significantly greater than AP (Δ: 14.7%, ES: 1.14).

Mechanical Fatigue

There was a statistically significant session x time interaction for mean velocity [F (4, 52) = 2.924, η_p^2 = 0.184, ω^2 = 0.012] and peak velocity [F (4, 52) = 2.635, η_p^2 = 0.169, ω^2 = 0.010]. Post hoc comparisons for the session x time interactions are displayed in Figure 2. Irrespective of group, the mean velocity during CL at pre was significantly greater than 5-min post (Δ: 3.3%, ES: 0.62) (Figure 2A). Similar results were observed with peak velocity between pre and 5-min post (Δ: 6.0%, ES: 0.79) (Figure 2B).

There was also a statistically significant between-subjects main effect for mean velocity [F (1, 13) = 6.201, η_p^2 = 0.323, ω^2 = 0.157] and peak velocity [F (1, 13) = 10.898, η_p^2 = 0.456, ω^2 = 0.261]. Furthermore, there was a statistically significant within-subjects main effect of time for peak velocity [F (1.420, 29.295) = 6.177, η_p^2 = 0.322, ω^2 = 0.046]. Irrespective of session, mean and peak velocity measured pre, 5-min post, and 10-min post were significantly greater in G2 when compared to G1 (mean velocity Δ: 6.6%, ES: 1.09; peak velocity Δ: 11.5%, ES: 1.48) (Table 2).

Set-RPE, Enjoyment, Session-RPE, Discomfort, and Affect

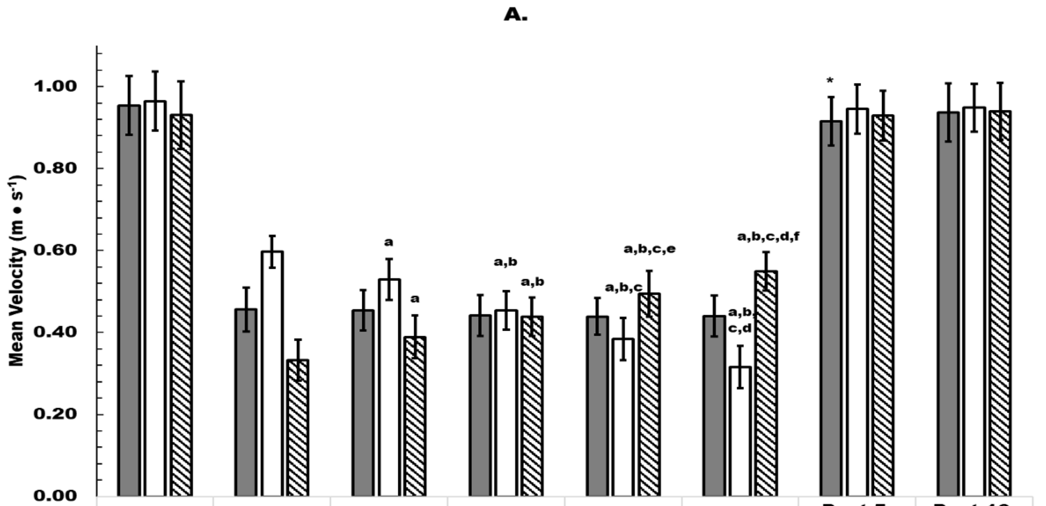
There was a statistically significant session x set interaction [F (1.816, 29.030) = 30.312, η_p^2 = 0.655, ω^2 = 0.378] and within-subject main effect on session [F (2, 32) = 5.905, η_p^2 = 0.270, ω^2 = 0.057] for set-RPE. Post hoc comparisons for set-RPE are displayed in Figure 4. Irrespective of group and set, set-RPE was significantly greater during AP when compared to DP (Δ: 7.1%, ES: 0.50) (Table 3).

It is noteworthy to mention that the set-RPE of set 1 during DP was significantly greater than AP and CL (Δ DP vs AP: 28.6%, ES: 1.81; Δ DP vs CL: 17.4%, ES: 1.15). On the other hand, the set-RPE of set 4 (Δ DP vs AP: 28.6%, ES: 1.83; Δ DP vs CL: 20.6%, ES: 1.33) and set 5 (Δ DP vs AP: 45.8%, ES: 2.66; Δ DP vs CL: 28.8%, ES: 1.69) during AP and CL was significantly greater than DP. Furthermore, the set-RPE of set 5 during AP was significantly greater than CL (Δ: 13.2%, ES: 0.97). See Figure 4 for a visual depiction of these differences.

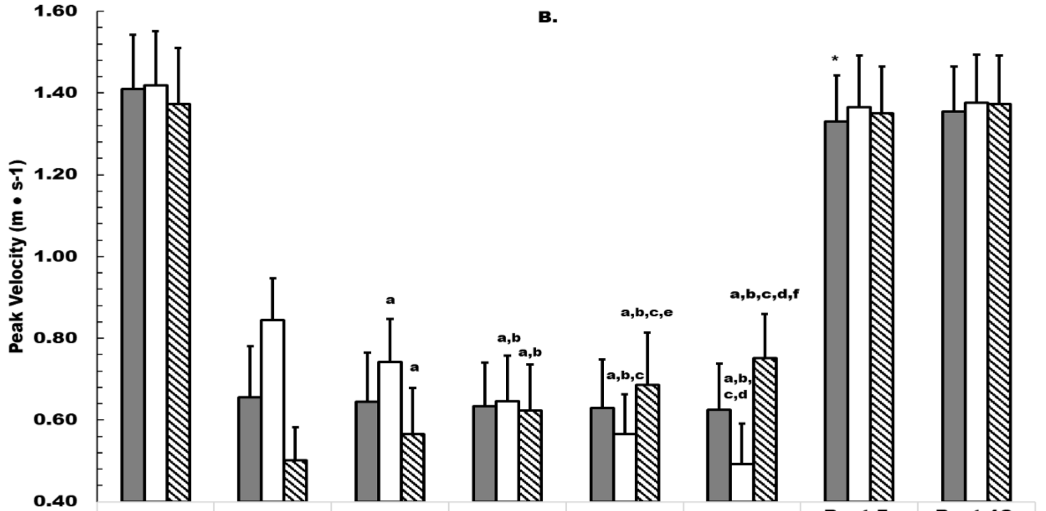
A statistically significant between-subject main effect on group, within-subject main effect on session, and group x session interaction was not observed for enjoyment (marginal mean ± SD; n = 18; 105 ± 15), session-RPE (5.2 ± 1.2), discomfort (2.1 ± 1.6), and affect (4 ± 1).

DISCUSSION

The present study compared the acute effects of AP, CL, and DP set configurations on repetition performance, TVL, barbell velocity, perceptual variables and mechanical fatigue. The results indicated that the average peak velocity and set-RPE across the five sets were significantly lower during DP compared to AP, while no differences were detected between AP and CL, or DP and CL. Mechanical fatigue, as measured by barbell velocity with 45% 1-RM before and after the training session, was significantly higher at the 5-min post timepoint following the CL training session. Several session x set interactions were also observed, but most of these differences are likely explained by the fluctuations in relative intensity that are intrinsic of pyramid training systems. For example, given the inverse relationships between load/velocity ( ), and



	Pre	Set 1	Set 2	Set 3	Set 4	Set 5	Post 5-min	Post 10-min
CL	0.95	0.46	0.45	0.44	0.44	0.44	0.92	0.94
AP	0.96	0.60	0.53	0.45	0.38	0.32	0.95	0.95
DP	0.93	0.33	0.39	0.44	0.49	0.55	0.93	0.94



	Pre	Set 1	Set 2	Set 3	Set 4	Set 5	Post 5-min	Post 10-min
CL	1.41	0.66	0.64	0.63	0.63	0.63	1.33	1.36
AP	1.42	0.84	0.74	0.65	0.57	0.49	1.37	1.38
DP	1.37	0.50	0.57	0.62	0.69	0.75	1.35	1.37

Figure 2. Mean (A) and peak (B) velocity recorded during ascending pyramid (AP), constant load (CL), and descending pyramid (DP) training sessions.

*Figure 2 Note: Significant post-hoc comparisons are shown above, and data are mean ± standard deviation (n =18). [a] Indicates significantly different than Set 1 within session, $p \leq 0.05$; [b] indicates significantly different than Set 2 within session, $p \leq 0.05$; [c] indicates significantly different than Set 3 within session, $p \leq 0.05$; [d] indicates significantly different than Set 4 within session, $p \leq 0.05$; [e] indicates significantly lower than AP Set 2 at same percentage of 1-RM (70%), $p \leq 0.05$; [f] indicates significantly lower than AP Set 1 at same percentage of 1-RM (65%), $p \leq .05$; *Indicates significantly lower than Pre, $p \leq 0.05$; $m \cdot s^{-1}$ = meters per second.*

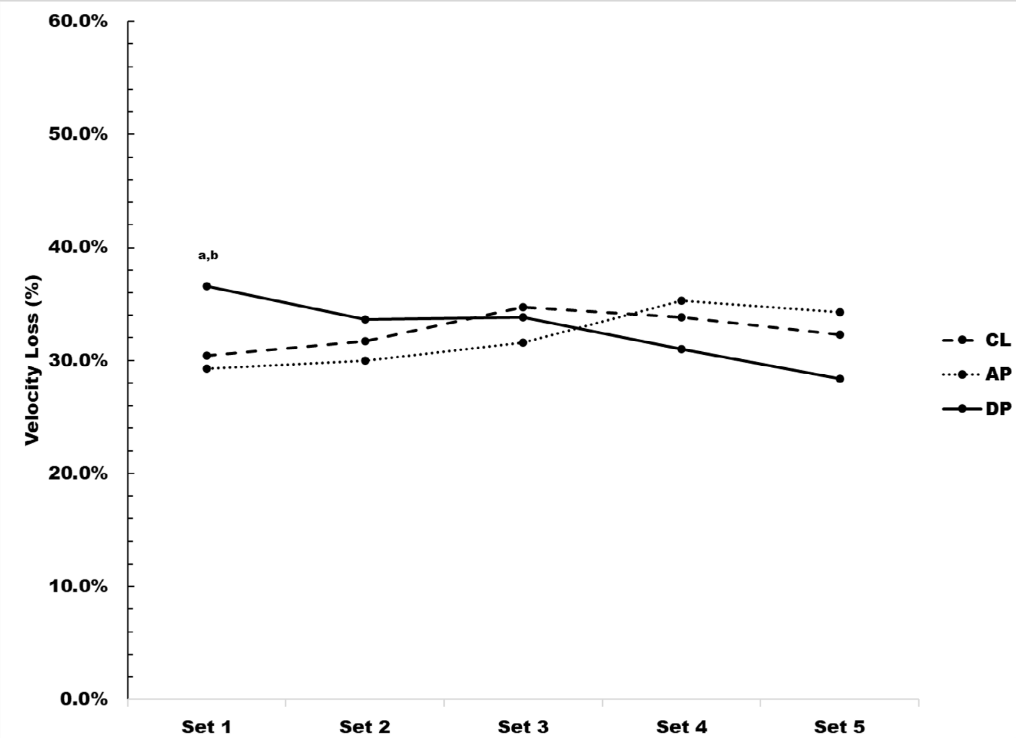


Figure 3. Velocity loss (VL) incurred during ascending pyramid (AP), constant load (CL), and descending pyramid (DP) training sessions.

Figure 3 Note: [a] Indicates DP is significantly greater than AP Set 1, $p \leq 0.05$; [b] indicates DP Set 1 is significantly greater than DP Set 5 within session, $p \leq 0.05$.

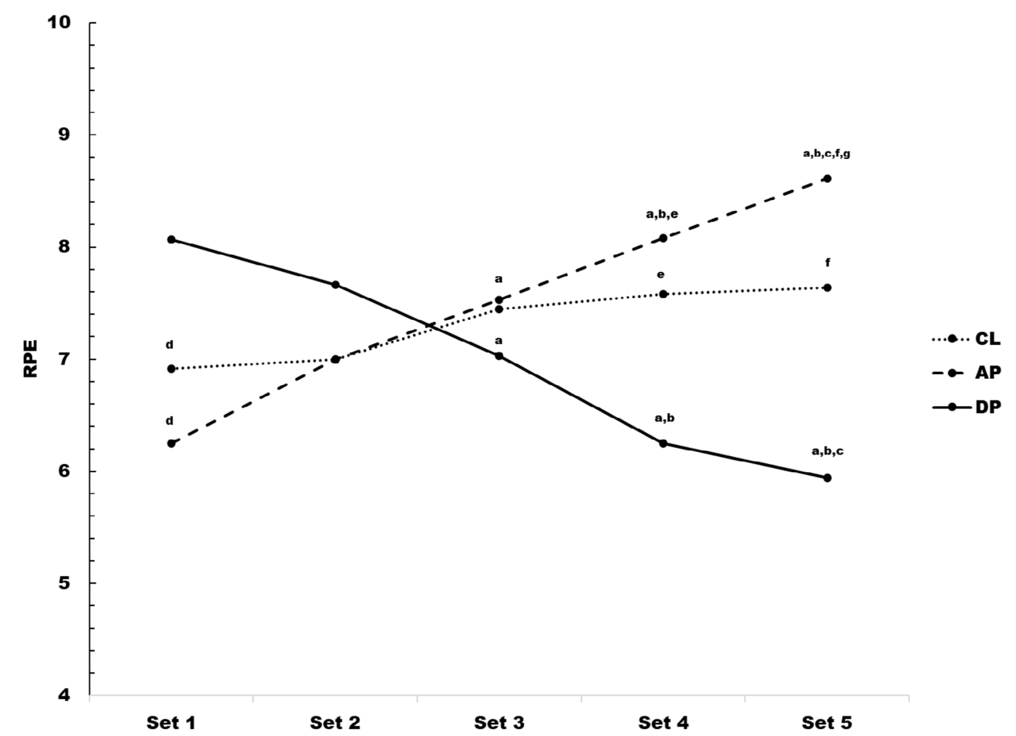


Figure 4. Ratings of perceived exertion (RPE) recorded after each set of ascending pyramid (AP), constant load (CL), and descending pyramid (DP) training sessions.

Figure 4 Note: [a] Indicates significantly different than Set 1 within session, $p \leq 0.05$; [b] indicates significantly different than Set 2 within session, $p \leq 0.05$; [c] indicates significantly different than Set 3 within session, $p \leq 0.05$; [d] indicates significantly lower than DP Set 1, $p \leq 0.05$; [e] indicates significantly greater than DP Set 4, $p \leq 0.05$; [f] indicates significantly greater than DP Set 5, $p \leq 0.05$; [g] indicates significantly different than CL Set 5, $p \leq 0.05$.

load/repetition performance (46), it makes sense that barbell velocity and total repetitions were both higher during sets completed with lower relative intensity (e.g., 65% 1-RM) compared to higher relative intensity (e.g., 85% 1-RM). Data also indicated that external load and TVL were significantly greater for G1 while mean velocity and peak velocity were significantly greater for G2. Thus, it seems that when relative intensity is matched, training volume and barbell velocity are influenced by the absolute external load lifted.

Total volume load did not significantly differ between sessions (CL = 2285 kg; AP = 2218 kg; DP = 2290 kg), a result that echoes previous studies that compared AP to CL (7, 8). For example, Charro et al. (8) reported that a session of AP training (3 sets of 64-74-80% 1-RM; 4862 kg) led to similar TVL as a session of CL training (3 sets of 75% 1-RM; 4642 kg). The session x set interaction for repetition performance suggests that because relative intensity varied set-by-set for AP and DP (65-85% 1-RM), the number of repetitions that could be successfully completed during each set varied as well (46). When relative intensity was matched, repetition performance did not differ between sessions (e.g., 8.5 reps with 65% 1-RM for Set 1 of AP vs. 8.2 reps with 65% 1-RM for Set 5 of DP). Consequently, our initial hypothesis, which predicted that repetition performance and TVL would be significantly greater during the DP protocol, was not corroborated by the study results. Post-activation potentiation research has demonstrated superior repetition performance and higher TVL during moderate-load, hypertrophy-style training (3-4 sets to failure, 70-75% 1-RM) when these sets were preceded by heavy-load, priming sets (1-2 sets, 2-3 reps, 90% 1-RM) (1, 9). It is possible that the relative intensities of the heavier sets in the present study were too low to stimulate PAP (80-85% 1-RM), or that any potential PAP was diminished by too much fatigue incurred during the heavier sets (45). Rest intervals should also be considered, as Alves et al. (1) separated the ‘priming sets’ and ‘hypertrophy-style sets’ by 10 min as opposed to the 5-min rest intervals used in the present study. Furthermore, we ceased each set at 25% VL compared to lifting to failure, which may have contributed to the non-significant results in our study compared to others (1, 9). Overall, training volume did not differ between sessions, and set-by-set differences for repetition performance likely reflect fluctuations in relative intensity.

Session x set interactions were observed for mean and peak velocity. More specifically, when lower external loads were lifted, mean and peak velocities were higher, and vice versa, which exemplifies the inverse relationship between load and velocity (18). Mean velocities were higher during set 1 (65% 1-RM = 0.60 $m \cdot s^{-1}$) and set 2 (70% 1-RM = 0.53 $m \cdot s^{-1}$) of AP when compared to set 5 (65% 1-RM = 0.55 $m \cdot s^{-1}$) and set 4 (70% 1-RM = 0.49 $m \cdot s^{-1}$) of DP. Similarly, peak velocities were higher during set 1 (65% 1-RM = 0.84 $m \cdot s^{-1}$) and set 2 (70% 1-RM = 0.74 $m \cdot s^{-1}$) of AP when compared to set 5 (65% 1-RM = 0.75 $m \cdot s^{-1}$) and set 4 (70% 1-RM = 0.69 $m \cdot s^{-1}$) of DP. This demonstrates the absence of a PAP effect (24, 30), and suggests that barbell velocity is compromised when sets are performed with a DP configuration. Previous researchers reported no difference in PAP between AP and DP as measured by muscle activation during sets of unilateral elbow flexion (30). Disparate outcomes between studies can be explained by differences in relative intensity (65-85% 1-RM vs. 75-100% 10-RM), rest intervals (5 vs. 3 min) or exercises (bench press vs. bicep curl). Regardless of set configuration, G2 recorded significantly higher mean and peak velocities compared to G1, indicating that differences in relative strength and absolute external load influenced barbell velocity. In support of these findings, a previous study demonstrated that ‘weak’ male lifters (RSR = 1.02 ± 0.08) produced higher barbell velocity than ‘strong’ male lifters (RSR = 1.32 ± 0.13) during sets of bench press (47). Interestingly, Torrejon et al. reported that ‘weak men’ registered higher velocities between 30-80% 1-RM while ‘strong men’ registered higher velocities at 90-100% 1-RM (47). It is plausible that stronger men produce higher velocities at greater relative intensities because they have more experience and skill when using such relative loads (47). In the present study, we speculate that differences in barbell velocity between weaker and stronger men were influenced more by the absolute load lifted (e.g., 72.2 vs. 90.5 kg) than the matched relative intensity (e.g., 75% 1-RM). Collectively, mean and peak velocity were significantly lower during specific sets of DP compared to AP and CL, and weaker lifters generally exhibited faster barbell speed than stronger lifters.

Besides Set 1 of DP, VL did not differ between sets and training sessions, which implies good experimental control and similar fatigue levels (AP = 31.8%; CL = 32.7%; DP = 32.2 %). Although the VL during sets 2-5 were similar between AP, CL, and DP, the VL was generally higher when higher relative intensities were used (80-85% vs. 65-70% 1-RM). For example, a large effect size (ES: 1.27) was observed between sets 1 and 5 of DP (65 vs. 85% 1-RM) as well as between set 1 of DP (85% 1-RM) and set 1 of AP (65% 1-RM) (ES: 1.14). This indicates that the VL between successive repetitions is not uniform across relative loads, and the slope of VL may be steeper when heavier relative loads are lifted. Previous research supports this concept, as Gonzalez-Badillo et al. (15) retroactively compared the percentage of total repetitions completed at various VL when sets were performed to momentary failure. The authors reported that when higher relative loads were used (75-85% 1-RM), the percentage of total repetitions completed was greater for any given magnitude of VL compared to lighter relative loads (50-70% 1-RM) (15). This area of research is under explored, and future studies can evaluate rep-to-rep VL patterns while applying a variety of relative loads. Generally, VL did not significantly differ between conditions in the present study, and minor differences between sets may be influenced by fluctuations in relative load.

Session x time interactions were observed for mechanical fatigue (i.e., mean and peak velocity with 45% 1-RM), but post-hoc comparisons revealed the only significant difference took place between pre and 5-min post for CL. This outcome is contrary to previous studies (11, 40). For example, da Vasconcelos Costa et al. (11) demonstrated that one session of DP training significantly decreased countermovement jump performance (-2.3%) while a session of CL training did not (-1%). Contrarily, Sabido et al. (40) reported that CL (-15.7%) and DP (-13.1%) training sessions significantly decreased peak velocity during bench press throw with no differences detected between conditions. In both studies, it was not specified when mechanical fatigue was measured (40) or the timepoints for measurement were different than ours (i.e., 30-min post) (11). Regardless, in the present study, barbell velocity recovered to pre-test values by the 10-min timepoint during CL, suggesting that post-exercise mechanical fatigue was minimal. Mean and peak velocities were significantly higher for G2, which again indicates that ‘weaker’ lifters produce higher barbell velocities than their ‘stronger’ counterparts, especially at lower relative intensities (e.g., 45% 1-RM) (47). Besides the slight differences observed between pre and 5-min post during CL, mechanical fatigue did not differ between sessions.

Data revealed a significant session x set interaction for set-RPE, and the post-hoc comparisons suggest this may be influenced by fluctuations in relative intensity. For example, set-RPE generally increased during AP, decreased during DP, and did not change during CL. It is plausible that sets conducted with heavier external loads were completed closer to momentary failure because they began with a lower initial velocity. To illustrate this point, let us consider the mean velocity of the first and last repetition completed during set 1 and set 5 during the AP training session. For set 1 (65% 1-RM), lifters in this study began at 0.69 $m \cdot s^{-1}$ and finished at 0.49 $m \cdot s^{-1}$. In contrast, for set 5 (85% 1-RM), lifters began at 0.37 $m \cdot s^{-1}$ and finished at 0.24 $m \cdot s^{-1}$. The reported barbell velocity for momentary failure during bench press is 0.12-0.19 $m \cdot s^{-1}$ (6). Thus, when heavier external loads were lifted, the 25% VL threshold caused these sets to be terminated closer to momentary failure, which led to higher set-RPE (28, 48). Considering the main effect for session, it is noteworthy that set-RPE was lower during DP compared to AP (7 vs. 7.5), a difference that yielded a moderate effect size (ES: 0.50). Post-hoc comparisons indicated that the overall difference between DP and AP was likely driven by significant differences observed during set 4 (DP = 6; AP = 8) and set 5 (DP = 6; AP = 8.5).

There were no significant differences between AP, CL, or DP for affect, discomfort, session-RPE, or enjoyment. Previous investigations also found no differences in session-RPE when CL was compared to AP (7, 29) and DP (40), which may reflect that hormonal concentration, metabolic stress, and muscle damage do not differ between sessions (2, 7, 8, 29, 40). Contrarily, Hutchison et al. (21) reported that enjoyment and motivation were higher during DP compared to AP. Disparities between studies may be explained by differences in training modalities (total-body circuit vs. bench press), relative intensity (55-75% vs. 65-85% 1-RM), or training status (untrained vs. trained). To summarize, most perceptual variables did not differ between sessions, but set-RPE increased with external load, and the average values for DP across the five sets were significantly lower than AP.

The current study’s findings must be interpreted within the context of several limitations. The participant pool was comprised of 18-40-year-old males with prior RT experience, suggesting that extrapolation of results to different demographics should be approached with caution. Furthermore, the data were derived from bench press training sessions characterized by predetermined variables such as set volume, relative intensity ranges, repetition tempo, and rest intervals, which may not translate directly to other exercises or training protocols. Additionally, the use of the TENDO analyzer did not account for potential variations in horizontal barbell displacement between repetitions, which could have impacted the results. The consistency of effort and performance across repetitions, despite subjects' familiarization with the required repetition tempo and concentric action, also presents a variable potentially affecting the uniformity of the data. Particularly notable was the application of a 25% VL threshold for set termination, which could result in premature cessation of a set if technique wavered momentarily, potentially not reflecting the true fatigue state. While not always statistically significant, the observation that absolute VL values increased with higher relative intensities suggests that VL progression is not uniform across sets and may affect RPE and fatigue metrics. Lastly, the assumption that participants adhered to pre-visit guidelines on diet, exercise, and hydration remains unverified, introducing another layer of variability to the study conditions.

To conclude, the present data indicate that repetition performance, TVL, mean velocity, affect, discomfort, enjoyment, and session-RPE do not differ between AP, CL, and DP set configurations during bench press. In contrast, peak velocity and set-RPE were significantly lower during DP compared to AP and CL. Although the absolute differences were small, mechanical fatigue was significantly higher at the 5-min post timepoint following the CL training session. Because these outcomes are specific to bench press, future research should apply AP, CL, and DP to other primary lifts such as squat and deadlift. From a practical perspective, strength and conditioning professionals should consider implementing AP, CL, or DP training sessions when their programs are hypertrophy and/or strength oriented. These set configurations can be implemented within a variety of effective training schemes, such as block, linear, and reverse periodization (13). If increasing barbell velocity is the primary training goal, incorporating AP and CL may be better options because mean and peak velocity were compromised during the DP session. The present data also indicate that mean and peak velocity were significantly greater for those with lower relative strength. However, we caution against making programming decisions based on these data because they are strictly observational and are not indicative of long-term adaptations. Instead, it may be prudent to create load-velocity profiles for individual athletes and aim to improve barbell velocity at relative loads where they are most deficient (22).

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