Changes in Bench Press Velocity and Power After 8 Weeks of High-Load Cluster- or Traditional-Set Structures

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Abstract

Davies, TB, Halaki, M, Orr, R, Helms, ER, and Hackett, DA. Changes in bench press velocity and power after 8 weeks of high-load cluster- or traditional-set structures. *J Strength Cond Res* 34(10): 2734–2742, 2020—This study investigated the effects of high-load cluster- vs. traditional-set structures using the bench press on velocity and power. Twenty-one resistance-trained individuals (male = 12, female = 9) performed a 3-week familiarization block followed by randomization into 1 of 2 upper- and lower-body split training routines performed for 8 weeks. The bench press was the only exercise manipulated with subjects using either cluster-set (CLUS, n = 11) or traditional-set (TRAD, n = 10) structures during training sessions. Subjects performed 4 sets of 5 repetitions at 85% 1 repetition maximum (1RM) with CLUS having a 30-second inter-repetition, and 3-minute interset rest while TRAD had a 5-minute interset rest. A load-velocity profile of relative loads derived from a 1RM test was used to assess velocity and power (absolute and relative to body mass) on the bench press. Significant improvements over time were found across various loads ranging from 45 to 75% 1RM for absolute and relative peak power (p = 0.006–0.041), and mean power (p = 0.001–0.032). Significant decreases over time were found at 55% 1RM and 65% 1RM for peak velocity (p = 0.027 and p = 0.012, respectively) and mean velocity (p = 0.047 and p = 0.022, respectively). There were no significant group or group by time interactions found for all outcomes. Within the context of high-load resistance training, set structure seems to be of less importance for changes in bench press velocity and power provided there is an intention to lift with maximal concentric velocity.

Key Words: fatigue, inter-repetition rest, load-velocity profile, linear position transducer, high loads

Introduction

Muscular power is the rate of performing work or the product of the applied force on an object and the velocity at which that object is moved in the same direction as the force (18). Success in sports that involve jumping, sprinting, and throwing is associated with the ability to generate higher muscular power outputs (24). Also, the capacity to generate muscular power is of great importance for other populations, such as the elderly, because of its role in enhancing physical function and performance of activities of daily living (35). Muscular power can be developed through resistance training using a wide range of loads, repetitions, sets, rest periods, and exercises (7). During training sessions targeting muscular power, there is an emphasis on lifting loads explosively which has been shown to be a vital stimulus to optimize the capacity to generate muscular power and elicit necessary neuromuscular adaptations (4). Many studies have shown that the actual movement velocity used during repetitions may influence the development of muscular power (19,26,29). However, a limited number of studies have found that the intention to lift explosively, despite fast actual movement velocities not being achieved, may be the essential stimulus for the development of muscular power (4,11). Thus, it seems that fast actual movement velocities and the intention to lift explosively are both critical stimuli in optimizing adaptations to enhance muscular power output.

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During traditional resistance training, fatigue will accumulate and gradually reduce the actual movement velocity throughout a set, thus decreasing muscular power output, until momentary muscular failure occurs (22). This fatigue-induced reduction in movement velocity during traditional sets may reduce the effectiveness of the training stimulus when targeting muscular power. Also, muscular strength, a significant contributor to muscular power output (6,41), has been shown to be optimally developed with the use of heavy loads (≥80% 1 repetition maximum [1RM]) (40). Therefore, manipulation of training variables to produce higher actual movement velocities, when using such loads, may be advantageous for the development of muscular power. One strategy to maintain a high actual movement velocity throughout a set is known as a cluster-set structure, which incorporates preplanned rest periods within sets (17). Acute studies have shown that this unique set structure allows the lifter to maintain or possibly increase movement velocity and muscular power compared with traditional-set structures across sets (22,43). The superior kinematic responses within cluster-set structures, attributable to the frequent rest periods within an individual set, may allow for optimization of movement velocity and improved muscular power adaptations (43).

Despite this logical inference, very few studies have directly investigated the effect of resistance exercise set structure on the change in movement velocity and power output, particularly after upper-body resistance training (28,34). Lawton et al. (28) found that cluster- and traditional-set structures resulted in similar improvements in muscular power output in the bench throw exercise after 6 weeks of moderate-load bench press training in youth athletes. By contrast, Oliver et al. (34) showed that muscular power was enhanced to a greater degree through the use of a cluster-set structure compared with a traditional-set structure after moderate-intensity high-volume bench press training in military personnel. Neither study assessed changes in movement velocity after the intervention. Currently, there is no consensus on whether cluster- or traditional-set structures are superior for the development of upper-body movement velocity and muscular power, and there is a lack of data investigating the effects when using high loads. The inconsistency may be the result of variance in methodological procedures such as which acute training variables are manipulated (e.g., load, repetitions per set, and exercises performed), intervention duration, and assessment protocol.

The aim of this study was to compare the effects of cluster- and traditional-set structures on bench press movement velocity and muscular power output after high-load resistance training. It was hypothesized that the cluster-set structure would lead to superior increases in bench press movement velocity and power output compared with the traditional-set structure.

Methods

Experimental Approach to the Problem

A randomized comparative design was used with testing occurring before and after intervention. Confounding variables known to influence the improvement in muscular strength, power and barbell velocity such as volume, load, and exercise order were all controlled between groups. Subjects were required to maintain habitual physical activity and nutritional intake while participating in the study. After baseline testing, all subjects completed the same 3-week familiarization phase to standardize previous resistance training experience. Subjects were then randomized into 1 of 2 intervention groups CLUS and TRAD. The intervention period consisted of an 8-week full-body resistance training program consisting of an upper- and lower-body split routine. Briefly, 6–8 weeks is considered to be the minimal training duration for the detection of significant neuromuscular adaptations (12). Therefore, it seemed plausible that using an 8-week intervention as opposed to a longer intervention might assist with study recruitment, adherence, and compliance. Both groups followed identical programs apart from bench press in each upper-body session which differed in set structure. CLUS performed 4 sets of 5 repetitions at 85% 1RM with 30 seconds of inter-repetition rest and 3 minutes of interset rest (i.e., the accumulation of single repetitions within a set). TRAD performed the same bench press prescription, although there was no inter-repetition rest period (i.e., continuous repetitions within each set) and 5 minutes of interset rest (Table 1). Post-testing occurred ≥48 hours after the completion of the intervention period.

Subjects

Twenty-two resistance-trained individuals, (9 women and 13 men, aged between 19–43 years), volunteered to participate in the study. Immediately after pre-testing, 1 male subject withdrew from the study because of a pre-existing shoulder injury. As the subject did not begin training, he was excluded from the analysis procedures. Therefore, 21 individuals completed all testing and training procedures. All subjects were regularly participating in resistance training consisting of the bench press immediately before the study. Each subject was risk stratified and deemed to be healthy to participate in the study. Subjects were excluded if they declared using

Table 1

Resistance training protocol for the bench press exercise across the familiarization and intervention phases.*

Familiarization		
Sets × repetitions	3 × 8	
Inter-repetition rest period	N/A	
Interset rest period	3 min	
Relative load (%1RM)	70–75% 1RM	
Intervention	**ICLUS**	**ITRAD**
Sets × repetitions	4 × 5	
Inter-repetition rest period	30 s	N/A
Interset rest period	3 min	5 min
Relative load (%1RM)	85% 1RM	

*1RM = 1 repetition maximum; CLUS = cluster-set group; TRAD = traditional-set group.

performance-enhancing substances (e.g., anabolic steroids) in the past 12 months or were younger than 18 years. According to the Cooper Institute normative data (5), relative bench press strength levels of subjects indicated that male subjects were of "fair" strength, while female subjects were of "poor" strength (relative bench press strength [kg per kg of body mass]: men = 1.07 ± 0.15; women = 0.58 ± 0.12). Subjects were randomly allocated to either CLUS (n = 11; men: n = 7, women: n = 4; age: 26.10 ± 7.10 years; resistance training experience: 3.78 ± 3.64 years; body mass: 74.24 ± 9.99 kg; bench press 1RM: 66.59 ± 23.16 kg) or TRAD (n = 10; men: n = 5, women: n = 5; age: 24.59 ± 6.90 years; resistance training experience: 5.10 ± 7.72 years; body mass: 75.57 ± 9.73 kg; bench press 1RM: 64.00 ± 29.28 kg). Subject characteristics were measured mean ± SD. Subjects were informed of the study purposes, procedures provided, and all potential risks and benefits before consent were obtained using an approved document from the university. Written informed consent was given by all subjects before commencing the study, which was approved by the University of Sydney Human Research Ethics Committee (Project Number: 2016/018).

Procedures

Familiarization and Resistance Training Intervention. The 3-week familiarization period was completed by all subjects and involved 2 upper-body sessions and 1 lower-body session per week of the same resistance training program amounting to a total of 9 sessions. After randomization, subjects completed 2 upper-body sessions and 1 lower-body session per week for 4 weeks (i.e., 12 training sessions for the first 4 weeks). For the final 4 weeks of the intervention, subjects completed 2 upper-body and 2 lower-body sessions per week (i.e., 16 training sessions for the second 4 weeks). All subjects performed the same resistance training program with only the bench press exercise being manipulated (Table 1).

Before each upper-body training and testing session, subjects performed a general warm-up of the shoulder rotator cuff muscles and upper back musculature, which included band-resisted shoulder external rotations and rear-delt flyes. After the general warm-up, subjects performed a specific warm-up using the bench press with 5 repetitions at approximately 50% of the subjects' targeted training load followed by another 5 repetitions at 75% of the subjects' targeted training load. During all repetitions of the bench press, subjects were encouraged to perform the eccentric phase in a controlled manner (~1–2 seconds) and the concentric phase with maximal concentric velocity. A 1RM bench press (procedures described below) was performed on a fortnightly basis to ensure the training load was maintained throughout the intervention period. All training sessions were directly supervised by an accredited and experienced powerlifting coach to ensure each subject adhered to the training prescription and performed all exercises safely. Subjects were instructed not to perform any other resistance training while enrolled in the study.

Assessment of Upper-Body Muscular Strength. Upper-body muscular strength was assessed with a 1RM bench press using a standard 20-kg barbell and weight plates (Iron Edge, Glen Iris, Australia). For a lift to be deemed successful, the subjects' head, shoulders, and hips were required to remain in contact with the bench with the feet placed flat on the floor. The barbell had to contact the subjects' chest (approximately at the upper sternum) during the descent with control to limit bouncing off the chest and to protect the thoracic (rib) cage from injury. On the ascent, the barbell was pressed until full arm's length (full elbow lock-out). Subjects were encouraged to perform the ascent with maximum concentric velocity and were given strong verbal encouragement from the assessor.

After the upper-body general warm-up, subjects began their specific warm-up by performing 5 repetitions with the barbell, 5 repetitions at 50% 1RM, 5 repetitions at 70% 1RM, 1 repetition at 80% 1RM, and 1 repetition at 90% of estimated 1RM. After the specific warm-up, attempts to ascertain the 1RM occurred in a progressive manner. After a successful 1RM attempt, the barbell load was progressively increased by a minimum of 2.5 kg with a minimum of 3 minutes of rest between attempts. The 1RM test was performed on 2 occasions at each timepoint (before and after intervention) for reliability purposes with a minimum of 48 hours of rest between sessions. The best result of the 2 trials was used for analysis.

Assessment of Barbell Velocity and Power Output. Barbell velocity and power output were assessed by a load-velocity profile on the bench press using a standard 20-kg barbell and weight plates. To calculate loads accurately, the 1RM test was used at least 24 hours before the load-velocity profile. Velocity and power (peak and mean) were calculated using the GymAware linear position transducer (Kinetic Performance Technology, Mitchell, Australia) previously validated with the free-weight bench press (9,10). Concentric velocity ($m \cdot s^{-1}$) was calculated by dividing the barbell displacement by the total time of the lift (i.e., initiation of a vertical displacement measurement until the cessation of movement). Peak velocity is an instantaneous value and was measured as the highest change in displacement within an individual sampling period. Mean velocity was measured by the average change in displacement over all samples acquired. Concentric power (W) was measured by multiplying the force applied onto the barbell (i.e., barbell mass multiplied by the sum of acceleration of the barbell and gravitational acceleration) by the velocity of the barbell during the lift. Peak power was measured as the highest power achieved in an individual sample period. Mean power was calculated as the sum of each power collected at each sample divided by the total number of samples acquired (16). The load-velocity profile consisted of 6 relative loads from 45–95% of the previously measured 1RM in 10% increments. Subjects were instructed to perform 2 trials at each relative load with the following rest intervals between trials; 30 seconds at 45 and 55% 1RM, 1 minute at 65% 1RM, 2 minutes at 75% 1RM, and 3 minutes at 85% 1RM and 95% 1RM, respectively. Rest intervals given between each relative load was as follows; 1 minute between 45 and 55% 1RM, 2 minutes between 55 and 65% 1RM as well as 65–75% 1RM, and 3 minutes between 75 and 85% 1RM as well as 85 and 95% 1RM, respectively. After a general upper-body warm-up, a specific warm-up followed with 1 set at 20% 1RM for 10 repetitions. If 20% 1RM was lower than the minimum barbell load (20 kg), subjects performed 1 set of push-ups which was modified based on the subject's ability. The load-velocity profile was performed with the same relative load in post-testing to control for the change in muscular strength.

In addition, peak and mean velocity were used to assess muscular fatigue during training sessions because of the strong relationship between the ability to maintain velocity and neuromuscular fatigue (39). Velocity maintenance was assessed at the midpoint of the training program for all subjects. The ability to maintain barbell velocity within each set was calculated using an equation similar to that used by Tufano et al. (43). Briefly, the maintenance equation takes into account every repetition performed rather than only the first and last repetitions which are used in traditional velocity loss calculations. This formula was adjusted to represent total deviation from the first repetition within a set and within a session. Therefore, a 100% maintenance indicates no deviation from the first repetition (i.e., total maintenance), while a value that is lower or higher than 100% indicates a negative (i.e., a decrease in velocity) or positive (i.e., an increase in velocity) deviation, respectively. The modified equations for velocity maintenance within sets and session are as follows:

Equation 1: Maintenance of barbell velocity across a full training session.

$$\text{Maintenance Velocity}_{\text{total}}(\%) = \left(\frac{\text{Mean Velocity}_{\text{session}} - \text{Velocity}_{\text{Repetition 1}}}{\text{Velocity}_{\text{Repetition 1}}}\right) + 1. \quad (1)$$

Equation 2: Maintenance of barbell velocity within each set.

$$\text{Maintenance Velocity}_{\text{set}}(\%) = \left(\frac{\text{Mean Velocity}_{\text{set}} - \text{Velocity}_{\text{Repetition 1}}}{\text{Velocity}_{\text{Repetition 1}}}\right) + 1. \quad (2)$$

Statistical Analyses

Baseline characteristics of all subjects were analyzed using independent *t*-tests. Primary effects of resistance training on power and velocity were analyzed using a 2 × 2 (group by time) repeated-measures analysis of variance with a post hoc Bonferroni adjustment. Analysis of within-group changes from baseline in all outcomes were analyzed using paired *t*-tests, while velocity maintenance within individual sets and the total session were assessed using an independent-sample *t*-test. All analyses were performed using SPSS (Version 20) software for Windows (SPSS, Chicago, IL, USA) and Excel (2016) software for Windows (Microsoft, Redmond, WA, USA). Reliability of the load-velocity profile was calculated using intraclass correlation coefficients (ICCs) and the coefficient of variation (CV) with 95% confidence intervals for both analyses (43). The results of the ICC were interpreted as <0.5 poor, 0.5–0.75 moderate, >0.75–0.9 good, and >0.9 excellent reliability (27). Coefficient of variation scores that were <5% were considered good reliability, 5–10% were considered moderate, and >10% were considered poor reliability (2). Estimates of effect size (ES) were calculated using standardized differences in mean values (Cohen's *d*, mean difference divided by pooled *SD*) (Comprehensive Meta-Analysis, Biostat, Englewood, NJ, USA) for between-group effects. The independent-group ES was used for within-group effects as suggested by Morris and DeShon (31). Effect size were interpreted in within-subject analyses as <0.3, 0.9, 1.6, 2.5, and >4.0 for trivial, small, moderate, large, very large, and extremely large effects, respectively (21). With between-subject analyses, ES was interpreted as <0.2, 0.6, 1.2, 2.0, and >4.0 for small, moderate, large, very large, and extremely large effects, respectively (21). For all analyses, an alpha level of significance was set at $p \leq 0.05$.

Results

Both groups significantly increased absolute and relative muscular strength before to after intervention with CLUS increasing by 9.90 ± 3.60% ($p < 0.001$, ES = 1.94) and 8.55 ± 4.48% ($p = <0.001$, ES = 1.79) and the TRAD-set group increasing by 11.06 ± 7.65% ($p < 0.001$, ES = 1.84) and 12.16% ± 7.07% ($p < 0.001$, ES = 1.43). There was a significant time effect for absolute and relative muscular strength ($p < 0.001$); however, no significant group ($p = 0.968$ for absolute and relative muscular strength) or group by time interactions ($p = 0.923$ for absolute and $p = 0.421$ for relative muscular strength, respectively) were found. The ICC for the 1RM was 0.997 (excellent reliability) and the CV 1.15% (good reliability). A significant group by time interaction was found for body mass favoring the CLUS-set group ($p = 0.025$, ES = 0.11) with no significant time or group effect. The CLUS-set group significantly increased body mass by 1.26 ± 1.46% ($p = 0.019$, ES = 0.93) with no significant change for the TRAD-set group ($p = 0.704$. ES = −0.11).

Peak Velocity and Power

Results for peak velocity and absolute and relative peak power derived from load-velocity profiling are presented in Table 2, with ES data being presented in Table 3. Significant time effects were found for peak velocity at 55% 1RM ($p = 0.027$) and 65% 1RM ($p = 0.012$) with no significant group or group by time interactions found at any relative load. Significant time effects were found for absolute peak power at 45% 1RM ($p = 0.041$), 65% 1RM ($p = 0.013$), and 75% 1RM ($p = 0.006$). Significant time effects were also found for peak power relative to body mass at 65% 1RM ($p = 0.022$) and 75% 1RM ($p = 0.009$) with no significant group or group by time interactions being found for all peak power variables.

Results for the reliability of peak velocity and power measurements at 45–95% 1RM are presented in Table 4. The ICC for peak velocity ranged from 0.816 to 0.935 (good to excellent reliability) at 45–85% 1RM, whereas an ICC of 0.620 (moderate reliability) was found at 95% 1RM. The CV for peak velocity was ≤3.78% (good reliability) at 45–65% 1RM, 5.54% (moderate reliability) at 75% 1RM, 8.57% (moderate reliability) at 85% 1RM, and 13.50% (poor reliability) at 95% 1RM. For peak power, the ICC ranged from 0.923 to 0.989 (excellent reliability) at 45–85% 1RM, with an ICC of 0.778 (good reliability) at 95% 1RM. The CV for peak power was ≤4.75% (good reliability) at 45 and 65% 1RM, 6.15% (moderate reliability) at both 55 and 75% 1RM, whereas CV was 11.30% (poor reliability) at 95% 1RM.

Mean Velocity and Power

Results for mean velocity and absolute and relative mean power derived from load-velocity profiling are presented in Table 5 with ES data being presented in Table 3. Significant time effects were found for mean velocity at 55% 1RM ($p = 0.047$) and 65% 1RM ($p = 0.022$) with no group or group by time interactions being found across any relative load. Significant time effects were found for absolute mean power at 45% 1RM ($p = 0.010$), 55% 1RM ($p = 0.032$), 65% 1RM ($p = 0.025$) and 75% 1RM ($p = 0.001$). Significant time effects were also found for relative mean power at 45% 1RM ($p = 0.019$), 55% 1RM ($p = 0.030$), and 75% 1RM ($p = 0.002$). No group or group by time interactions for absolute and relative mean power were found at any relative load for all mean power variables.

Results for the reliability of mean velocity and power measurements at 45–95% 1RM are presented in Table 4. The ICC for mean velocity ranged from 0.762 to 0.905 (good to excellent reliability) at 45–75% 1RM, 0.614 (moderate reliability) at 95% 1RM, and 0.499 (poor reliability) at 85% 1RM. The CV for mean velocity was ≤4.95% (good reliability) at 45–65% 1RM, 5.89% (moderate reliability) at 75% 1RM, and ≥11.34% (poor reliability) at 85 and 95% 1RM. For mean power, the ICC ranged from 0.761 to 0.988 (good to excellent reliability) at 45–95% 1RM. The CV for peak power was ≤3.08% (good reliability) at 45 and 65% 1RM, 5.40 and 5.90% (moderate reliability) at both 55 and 75% 1RM, respectively, whereas CV was ≥11.41 (poor reliability) at 85 and 95% 1RM.

Maintenance of Barbell Velocity

Results for barbell velocity maintenance within sets and session are presented in Figures 1 and 2. Within individual sets, the CLUS-set group was superior compared with the TRAD-set group in mean velocity maintenance in sets 1 ($p = 0.002$), 2 ($p = 0.001$), and 4 ($p = 0.037$). The CLUS-set group was also superior in maintaining peak velocity compared with the TRAD-set group in set 1 only ($p = 0.043$) (Figure 1). The ability to maintain mean velocity throughout the session was greater for the CLUS-set group compared with the TRAD-set group ($p = 0.015$), while there was no significant difference in total peak velocity maintenance ($p = 0.125$) (Figure 2).

Discussion

This study aimed to compare the effect of CLUS- vs. TRAD-set structures using the bench press on movement velocity and power output in subjects with at least 6 months of resistance training experience. Because of greater movement velocities and power outputs reported during CLUS- compared with TRAD-set structures within training sessions (42,43), we hypothesized that we would observe superior increases in movement velocity and power output for the CLUS-set group. We found significant decreases in peak and mean movement velocity over time at only 2 relative loads (55 and 65% 1RM); however, there was no significant difference between groups. Furthermore, there were significant improvements in peak and mean muscular power after the intervention at relative loads lower than the training load (<85% 1RM); however, there were no significant differences between groups. No adverse events were observed or reported during the intervention period for both groups, and there was a high compliance rate (>90% for each group). The results of this study indicate that set structure does not seem to affect changes in movement velocity and muscular power after high-load resistance training if repetitions are performed with maximal concentric velocity when controlling for training volume and load.

When performing repetitions during a set of resistance exercise, there is a gradual reduction in concentric movement velocity as the set approaches momentary muscular failure (39). The drop in repetition performance is the result of decreased high-energy phosphate availability (14) and the accumulation of metabolic by-products, e.g., lactate and ammonia (15). Studies have shown that cluster-set structures better maintain maximal movement velocity compared with traditional-set structures, which may provide a superior stimulus for the improvement in movement velocity (22,43). The current study showed that CLUS- and

Table 2

Changes in peak bench press power and velocity after the intervention period.*†

	CLUS (n = 11) (paired t-test)			TRAD (n = 10) (paired t-test)			ANOVA (p)		
	Pre	Post	p	Pre	Post	p	T	G	G × T
45% 1RM									
Absolute (W)	562.25 ± 117.41	605.00 ± 145.03	0.027‡	611.50 ± 187.04	635.17 ± 179.40	0.417	0.041‡	0.640	0.523
Relative (W/BM)	7.29 ± 1.31	7.72 ± 1.60	0.028‡	7.77 ± 2.00	8.12 ± 1.88	0.392	0.055	0.628	0.818
Velocity (m·s^{-1})	1.42 ± 0.13	1.40 ± 0.11	0.532	1.45 ± 0.09	1.41 ± 0.13	0.394	0.267	0.727	0.576
55% 1RM									
Absolute (W)	555.30 ± 206.05	545.00 ± 162.18	0.761	469.00 ± 200.11	481.50 ± 225.80	0.058	0.452	0.501	0.211
Relative (W/BM)	7.20 ± 2.30	7.03 ± 1.80	0.695	6.15 ± 2.18	6.31 ± 2.60	0.031‡	0.452	0.484	0.161
Velocity (m·s^{-1})	1.25 ± 0.15	1.18 ± 0.12	0.026‡	1.17 ± 0.11	1.15 ± 0.12	0.498	0.027‡	0.294	0.169
65% 1RM									
Absolute (W)	474.36 ± 174.60	506.27 ± 189.74	0.071	440.70 ± 205.62	460.10 ± 210.96	0.063	0.013‡	0.643	0.513
Relative (W/BM)	6.27 ± 1.90	6.62 ± 2.02	0.101	5.77 ± 2.31	6.02 ± 2.40	0.090	0.022‡	0.565	0.683
Velocity (m·s^{-1})	1.04 ± 0.13	1.00 ± 0.14	0.256	1.00 ± 0.11	0.92 ± 0.12	0.015‡	0.012‡	0.259	0.389
75% 1RM									
Absolute (W)	421.18 ± 149.06	453.55 ± 174.64	0.064	386.40 ± 185.17	418.10 ± 185.52	0.040‡	0.006‡	0.646	0.975
Relative (W/BM)	5.59 ± 1.69	5.96 ± 1.97	0.089	5.06 ± 2.15	5.47 ± 2.09	0.052	0.009‡	0.558	0.862
Velocity (m·s^{-1})	0.83 ± 0.12	0.80 ± 0.14	0.315	0.78 ± 0.12	0.75 ± 0.09	0.367	0.171	0.316	0.861
85% 1RM									
Absolute (W)	361.18 ± 133.71	382.18 ± 170.04	0.286	322.70 ± 142.43	346.00 ± 164.72	0.120	0.073	0.581	0.904
Relative (W/BM)	4.82 ± 1.67	5.02 ± 2.02	0.430	4.23 ± 1.64	4.56 ± 1.91	0.098	0.101	0.508	0.684
Velocity (m·s^{-1})	0.63 ± 0.13	0.60 ± 0.16	0.439	0.60 ± 0.12	0.57 ± 0.11	0.257	0.205	0.501	0.941
95% 1RM									
Absolute (W)	306.73 ± 121.77	295.18 ± 122.22	0.598	232.00 ± 127.80	261.80 ± 121.34	0.301	0.599	0.303	0.240
Relative (W/BM)	4.07 ± 1.52	3.94 ± 1.61	0.675	3.08 ± 1.54	3.44 ± 1.42	0.318	0.621	0.252	0.293
Velocity (m·s^{-1})	0.48 ± 0.12	0.43 ± 0.15	0.242	0.42 ± 0.18	0.39 ± 0.09	0.495	0.190	0.333	0.784

*CLUS = cluster-set group; TRAD = traditional-set group; ANOVA = analysis of variance; Pre = pre-training/baseline testing; Post = post-training testing; G = group effect; T = time effect; G×T = group by time interaction; 1RM = 1 repetition maximum; W = watts; W/BM = watts per kilogram of body mass.

†Data presented as mean ± *SD*.

‡Significant (<0.05).

TRAD-set structures fail to improve movement velocity at all relative loads after high-load resistance training. In fact, ES calculations demonstrated that movement velocity tended to decline after training regardless of set structure, with 2 relative loads reaching statistical significance. Similarly, previous studies have shown no change in movement velocity after lower-body resistance training using different set structures (23,30). The optimal development of movement velocity seems to occur through the use of very light loads (25). Although a reasonable hypothesis that inclusion of inter-repetition rest periods and subsequently higher actual concentric movement velocities would enhance power or movement velocity at post-testing, this was not the case. Rather, no significant differences were observed between groups, perhaps, because high loads were used in both groups leading to similar neuromuscular responses (e.g., maximal motor unit recruitment and firing rates).

Power is defined as the rate (i.e., velocity) at which an applied force displaces an object (e.g., barbell) (18). Therefore, during resistance training as muscular fatigue develops, a decrease in movement velocity leads to a reduction in power output (14,22). Through the addition of inter-repetition rest periods, as used in the current study, there is a reduction in accumulated fatigue which facilitates higher power outputs across a set (43). However, there is a lack of consensus from previous studies on whether cluster- compared with traditional-set structures within upper-body resistance training programs offer any advantage in the development of muscular power. Studies examining set structure with the bench press used a subclass of cluster-sets called a rest-redistribution model (42), whereby the cluster-set group performed half the repetitions and double the sets of the traditional-set group using moderate-high loads with the same total rest accumulated (28,34). Lawton et al. (28) found that muscular power development was not different between groups when training with loads progressing to approximately 80% 1RM, whereas Oliver et al. (34) found greater muscular power development for the cluster-set compared with the traditional-set group when training with moderate loads (60–75% 1RM). The differences in training load prescribed between these 2 studies are likely a contributing factor to the lack of agreement. However, when using high loads, the results from Lawton et al. (28) and the current study seem to suggest that set structure does not influence the development of muscular power.

Changes in muscular power after high-load resistance training may be influenced by muscular strength development (i.e., maximal force output) rather than changes in movement velocity (8). As both CLUS and TRAD similarly increased muscular strength, it seems that the addition of inter-repetition rest periods (in an effort to produce larger power outputs during each set) does not promote the superior development of muscular power. There is a rudimentary association between muscular strength and muscular power in which high power outputs are produced by individuals who exhibit high levels of muscular strength (7). Stronger individuals who have extensive resistance training experience have superior morphological and neuromuscular profiles compared with weaker and less experienced individuals (12), which leads to positive shifts in an individual force-velocity relationship (32). Positive shifts in the force-velocity relationship indicate that force output will be higher with a given velocity which subsequently leads to larger power outputs (26). Moreover, the use of heavy loads in the current study may have led to a more favorable motor unit recruitment pattern compared to lighter loads (38). Henneman's size principle states high-threshold motor units, which innervate type II muscle

Table 3

Effect sizes for the change in peak and mean velocity and power.*†

	Within-group ES								Between-group ES			
	CLUS (n = 11)				TRAD (n = 10)							
	Peak		Mean		Peak		Mean		Peak		Mean	
	ES	95% CI of ES	ES	95% CI of ES	ES	95% CI of ES	ES	95% CI of ES	ES	95% CI of ES	ES	95% CI of ES
45% 1RM												
Absolute (W)	1.42	0.32 to 2.52	1.60	0.48 to 2.73	0.36	−0.78 to 1.50	0.56	−0.60 to 1.71	0.17	−0.90 to 1.22	0.12	−0.95 to 1.17
Relative (W/BM)	1.46	0.35 to 2.56	1.24	0.17 to 2.31	0.37	−0.77 to 1.51	0.54	−0.61 to 1.69	0.06	−1.01 to 1.11	0.07	−0.99 to 1.12
Velocity (m·s^{-1})	−0.46	−1.29 to 0.68	−0.19	−1.17 to 0.79	−0.47	−1.62 to 0.68	−0.40	−1.54 to 0.75	0.26	−0.82 to 1.31	0.10	−0.97 to 1.15
55% 1RM												
Absolute (W)	−0.10	−0.97 to 0.78	0.68	−0.18 to 1.54	0.84	−0.13 to 1.80	0.51	−0.43 to 1.45	−0.25	−1.14 to 0.67	−0.05	−0.93 to 0.83
Relative (W/BM)	−0.16	−0.72 to 1.04	0.50	−0.41 to 1.37	1.01	0.03 to 1.99	0.60	−0.35 to 1.54	−0.32	−1.21 to 0.60	−0.10	−0.98 to 0.78
Velocity (m·s^{-1})	−0.83	−1.74 to 0.09	−0.74	−1.64 to 0.17	−0.26	−1.19 to 0.67	−0.38	−1.27 to 0.50	−0.37	−1.26 to 0.56	−0.22	−1.11 to 0.69
65% 1RM												
Absolute (W)	0.66	−0.20 to 1.52	0.81	−0.06 to 1.68	0.69	−0.22 to 1.59	0.38	−0.50 to 1.27	0.07	−0.79 to 0.92	0.07	−0.79 to 0.93
Relative (W/BM)	0.57	−0.28 to 1.43	0.75	−0.11 to 1.62	0.63	−0.27 to 1.52	0.40	−0.49 to 1.28	0.05	−0.81 to 0.90	0.04	−0.81 to 0.90
Velocity (m·s^{-1})	−0.37	−1.21 to 0.48	−0.30	−1.14 to 0.54	−1.09	−2.03 to −0.15	−0.18	−1.06 to 0.70	0.41	−0.47 to 1.26	0.37	−0.50 to 1.22
75% 1RM												
Absolute (W)	0.78	−0.09 to 1.65	1.20	0.29 to 2.11	0.76	−0.15 to 1.66	0.72	−0.18 to 1.63	0.00	−0.85 to 0.86	0.01	−0.84 to 0.87
Relative (W/BM)	0.68	−0.18 to 1.54	1.10	0.06 to 1.82	0.69	−0.22 to 1.59	0.67	−0.23 to 1.57	−0.02	−0.88 to 0.84	−0.02	−0.87 to 0.84
Velocity (m·s^{-1})	−0.32	−1.16 to 0.52	−0.50	−1.34 to 0.35	−0.20	−1.08 to 0.68	−0.33	−1.21 to 0.55	−0.08	−0.93 to 0.78	0.00	−0.86 to 0.86
85% 1RM												
Absolute (W)	0.47	−0.37 to 1.32	0.39	−0.45 to 1.24	0.68	−0.22 to 1.58	0.36	−0.52 to 1.25	−0.02	−0.88 to 0.84	0.05	−0.81 to 0.91
Relative (W/BM)	0.30	−0.54 to 1.14	0.32	−0.52 to 1.16	0.71	−0.20 to 1.61	0.37	−0.52 to 1.25	−0.08	−0.93 to 0.78	0.02	−0.84 to 0.88
Velocity (m·s^{-1})	−0.25	−1.09 to 0.59	−0.41	−1.26 to 0.43	−0.32	−1.21 to 0.56	−0.76	−1.67 to 0.15	0.00	−0.86 to 0.86	0.31	−0.57 to 1.15
95% 1RM												
Absolute (W)	−0.17	−1.00 to 0.67	−0.14	−0.98 to 0.69	0.39	−0.54 to 1.32	0.38	−0.51 to 1.26	−0.33	−1.18 to 0.54	−0.34	−1.19 to 0.53
Relative (W/BM)	−0.13	−0.97 to 0.70	−0.10	−0.94 to 0.73	0.32	−0.61 to 1.25	0.41	−0.47 to 1.30	−0.32	−1.17 to 0.55	−0.35	−1.19 to 0.53
Velocity (m·s^{-1})	−0.38	−1.22 to 0.46	−0.18	−1.01 to 0.66	−0.16	−1.08 to 0.77	−0.19	−1.11 to 0.74	−0.13	−0.98 to 0.73	0.00	−0.86 to 0.86

*ES = effect size; CLUS = cluster-set group; TRAD = traditional-set group; CI = confidence interval; 1RM = 1 repetition maximum; W = watts; BM = body mass; W/BM = watts per kilogram of body mass.
†Data are presented as mean ± *SD*.

fibers, will be recruited when maximal forces are required (20). Consequently, the use of heavy loads during training involves greater recruitment of type II muscle fibers (38), which are imperative for the performance of powerful and high-intensity tasks. Therefore, any improvement in muscular power when using heavy loads is likely to have been driven by increases in muscular strength, rather than the maintenance or improvement of movement velocity using inter-repetition rest periods.

To the authors' knowledge, the current study is the first to assess movement velocity and muscular power across a spectrum

Table 4

Reliability analyses of peak and mean velocity and power across the tested relative loads.*

	45% 1RM	55% 1RM	65% 1RM	75% 1RM	85% 1RM	95% 1RM
Peak velocity (m·s^{-1})						
Trial 1	1.39 ± 0.11	1.16 ± 0.14	0.99 ± 0.11	0.77 ± 0.12	0.59 ± 0.14	0.46 ± 0.11
Trial 2	1.42 ± 0.12	1.19 ± 0.13	1.02 ± 0.12	0.79 ± 0.14	0.58 ± 0.13	0.46 ± 0.12
ICC (95 CI)	0.816 (0.521 to 0.937)	0.871 (0.697 to 0.948)	0.935 (0.847 to 0.973)	0.826 (0.619 to 0.925)	0.844 (0.655 to 0.934)	0.620 (0.213 to 0.843)
CV% (95 CI)	3.16 (2.05 to 4.26)	3.78 (2.67 to 4.90)	2.87 (2.04 to 3.70)	5.54 (3.07 to 7.80)	8.57 (5.83 to 10.90)	13.50 (7.98 to 19.03)
Peak power (W)						
Trial 1	560.64 ± 135.21	490.63 ± 197.07	431.67 ± 171.90	386.29 ± 162.46	324.29 ± 129.55	275.47 ± 109.77
Trial 2	569.79 ± 146.41	489.95 ± 175.86	457.38 ± 185.36	392.43 ± 165.37	323.38 ± 132.15	267.65 ± 114.29
ICC (95 CI)	0.954 (0.863 to 0.985)	0.923 (0.813 to 0.970)	0.989 (0.972 to 0.995)	0.970 (0.928 to 0.988)	0.937 (0.851 to 0.974)	0.778 (0.487 to 0.914)
CV% (95 CI)	4.41 (2.91 to 5.91)	6.15 (3.71 to 8.60)	4.75 (2.62 to 6.88)	6.15 (3.30 to 9.00)	8.34 (5.61 to 11.08)	11.30 (8.77 to 19.51)
Mean velocity (m·s^{-1})						
Trial 1	0.90 ± 0.10	0.79 ± 0.10	0.68 ± 0.07	0.54 ± 0.08	0.40 ± 0.10	0.25 ± 0.05
Trial 2	0.93 ± 0.10	0.79 ± 0.09	0.70 ± 0.08	0.55 ± 0.08	0.40 ± 0.07	0.24 ± 0.10
ICC (95 CI)	0.905 (0.730 to 0.968)	0.791 (0.535 to 0.914)	0.904 (0.780 to 0.960)	0.762 (0.501 to 0.896)	0.499 (0.097 to 0.761)	0.614 (0.205 to 0.841)
CV% (95 CI)	2.70 (1.20 to 4.19)	4.95 (3.46 to 6.44)	2.93 (1.91 to 3.94)	5.89 (3.57 to 8.22)	11.34 (2.05 to 20.64)	17.44 (8.47 to 26.41)
Mean power (W)						
Trial 1	323.29 ± 81.25	292.47 ± 100.30	280.62 ± 108.89	258.48 ± 261.57	207.14 ± 88.87	146.82 ± 55.64
Trial 2	335.50 ± 86.54	296.16 ± 110.44	288.29 ± 117.76	109.57 ± 106.90	211.05 ± 82.72	140.12 ± 68.78
ICC (95 CI)	0.972 (0.915 to 0.991)	0.967 (0.916 to 0.987)	0.988 (0.971 to 0.995)	0.980 (0.951 to 0.992)	0.842 (0.651 to 0.933)	0.761 (0.455 to 0.906)
CV% (95 CI)	3.08 (1.16 to 5.00)	5.40 (3.95 to 6.85)	2.92 (1.88 to 3.96)	5.90 (3.54 to 8.26)	11.41 (2.14 to 20.69)	16.62 (9.21 to 24.02)

*1RM = 1 repetition maximum; ICC = intraclass correlation coefficient; CI = confidence interval; CV = coefficient of variation; W = watts.

Table 5

Changes in mean bench press power and velocity after the intervention period.*†

	CLUS (n = 11) (paired t-test)			TRAD (n = 10) (paired t-test)			ANOVA (p)		
	Pre	Post	p	Pre	Post	p	T	G	G × T
45% 1RM									
Absolute (W)	324.50 ± 75.14	352.25 ± 89.26	0.013‡	352.86 ± 97.94	370.67 ± 110.59	0.201	0.010‡	0.647	0.484
Relative (W/BM)	4.20 ± 0.87	4.49 ± 1.21	0.023‡	4.47 ± 1.19	4.69 ± 1.24	0.258	0.019‡	0.684	0.724
Velocity (m·s^{-1})	0.92 ± 0.11	0.90 ± 0.09	0.493	0.95 ± 0.09	0.89 ± 0.12	0.372	0.225	0.618	0.628
55% 1RM									
Absolute (W)	316.70 ± 95.60	331.60 ± 92.63	0.060	293.11 ± 128.26	313.67 ± 135.02	0.181	0.032‡	0.692	0.713
Relative (W/BM)	4.14 ± 1.10	4.30 ± 1.07	0.182	3.84 ± 1.40	3.94 ± 1.53	0.132	0.030‡	0.403	0.234
Velocity (m·s^{-1})	0.83 ± 0.10	0.79 ± 0.07	0.021‡	0.80 ± 0.08	0.78 ± 0.11	0.527	0.047‡	0.649	0.322
65% 1RM									
Absolute (W)	298.55 ± 105.10	320.36 ± 117.99	0.044‡	282.30 ± 134.53	295.20 ± 136.13	0.261	0.025‡	0.703	0.540
Relative (W/BM)	3.96 ± 1.15	4.20 ± 1.23	0.043‡	3.68 ± 1.53	3.86 ± 1.55	0.254	0.054	0.393	0.560
Velocity (m·s^{-1})	0.71 ± 0.08	0.69 ± 0.09	0.231	0.70 ± 0.08	0.65 ± 0.10	0.050	0.022‡	0.436	0.485
75% 1RM									
Absolute (W)	279.73 ± 96.03	300.09 ± 101.86	0.004‡	257.50 ± 122.85	276.30 ± 123.97	0.050	0.001‡	0.640	0.875
Relative (W/BM)	3.71 ± 1.01	3.94 ± 1.04	0.005‡	3.36 ± 1.41	3.61 ± 1.39	0.062	0.002‡	0.522	0.868
Velocity (m·s^{-1})	0.59 ± 0.06	0.57 ± 0.07	0.244	0.55 ± 0.09	0.53 ± 0.07	0.217	0.084	0.220	0.769
85% 1RM									
Absolute (W)	234.73 ± 79.33	248.09 ± 99.32	0.328	211.00 ± 91.86	219.90 ± 105.00	0.361	0.186	0.527	0.786
Relative (W/BM)	3.12 ± 0.86	3.26 ± 1.13	0.437	2.76 ± 1.04	2.88 ± 1.20	0.358	0.245	0.422	0.924
Velocity (m·s^{-1})	0.44 ± 0.07	0.41 ± 0.10	0.422	0.42 ± 0.06	0.37 ± 0.08	0.075	0.067	0.333	0.497
95% 1RM									
Absolute (W)	167.18 ± 70.10	160.64 ± 63.20	0.633	113.60 ± 62.84	130.00 ± 72.54	0.304	0.628	0.144	0.265
Relative (W/BM)	2.21 ± 0.87	2.14 ± 0.85	0.742	1.50 ± 0.74	1.71 ± 0.87	0.331	0.640	0.107	0.354
Velocity (m·s^{-1})	0.27 ± 0.09	0.25 ± 0.09	0.508	0.21 ± 0.09	0.20 ± 0.06	0.608	0.401	0.059	0.870

*CLUS = cluster-set group; TRAD = traditional-set group; ANOVA = analysis of variance; Pre = pre-training/baseline testing; Post = post-training testing; G = group effect; T = time effect; G × T = group by time interaction; 1RM = 1 repetition maximum; W = watts; W/BM = watts per kilogram of body mass.
†Data presented as mean ± SD.
‡Significant (<0.05).

of relative loads taking into account changes in muscular strength after resistance training of different set structures. Typically, bench press power is measured using a fixed load (e.g., absolute load at baseline). If using a fixed load, the underlying mechanism (i.e., force production or movement velocity) behind an improvement in muscular power remains unknown. As a function of using a constant relative load in the current study, muscular power could be assessed while controlling for changes in a subject's muscular strength. Future studies on this topic should consider taking into account the individual change in muscular strength in conjunction with traditional measures when assessing power to ascertain the fundamental mechanism behind any improvement.

The current study showed that velocity and power measures when using a load-velocity profile were less reliable with heavier loads (≥85% 1RM). This is in agreement with previous research reporting poor reliability of velocity and power measurements for heavier compared with lighter load back squats (3). High

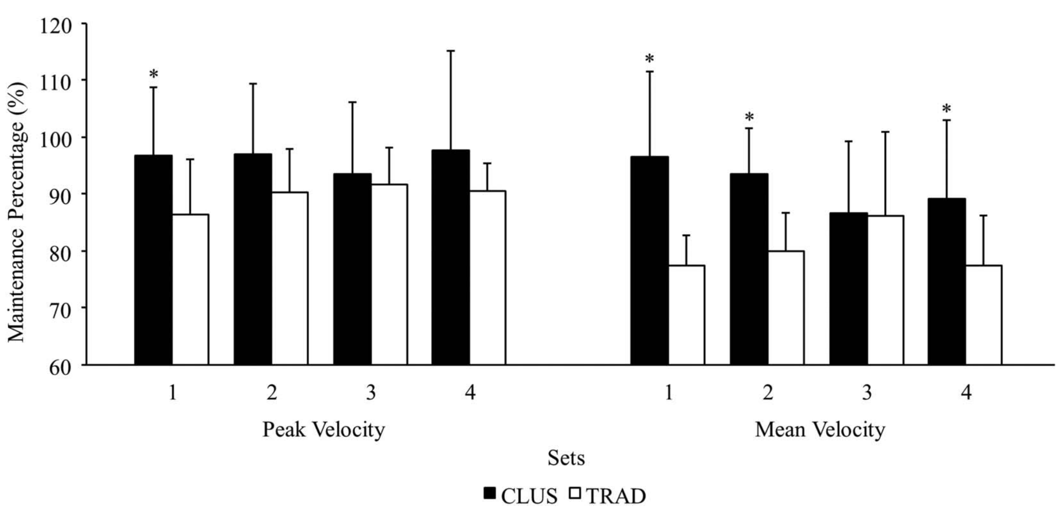

Figure 1. Peak and mean barbell velocity maintenance within each set. *p < 0.05 compared with TRAD for corresponding set. Data are mean ± SD. CLUS = cluster-set group; TRAD = traditional-set group.

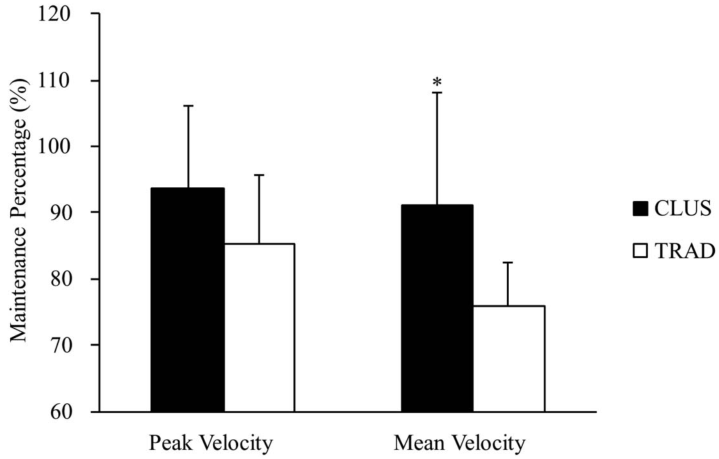

Figure 2. Total peak and mean barbell velocity maintenance. *$p < 0.05$ compared with TRAD. Data are mean ± *SD*. CLUS = cluster-set group, TRAD = traditional-set group.

reliability across a wide range of loads using the bench press when performing a load-velocity profile has also been demonstrated (13). However, a cautious note from the aforementioned study is that the bench press was performed using a Smith machine which enables all movement to remain in the same straight line, thus decreasing the risk of poor lift execution and, therefore, large alterations in velocity measurements. Based on the results of the current study, coaches should be cautious when interpreting velocity and power measurements for high to very high loads between sessions due to the presently reported reliability issues.

Although the 8-week training duration for the current study is considered to be at the upper end of the minimum training duration threshold (i.e., 6–8 weeks) for neuromuscular adaptations (12), it is possible that results could have differed with a longer duration. It should be noted that muscular hypertrophy seems to proceed in a linear manner during the first 6 months of training; however, there is a disproportionately larger increase in muscular strength than in cross-sectional area during the early weeks of a resistance training intervention (1,33). The neurological adaptations responsible for increases in muscular strength are related to coordination and learning of an exercise, which lead to improved activation of the muscles involved (36,37).

There are certain limitations in the design and implementation of this study which should be considered when interpreting the results. First, our measurement of power and velocity is highly specific to the bench press which may not extrapolate to other upper-body power tests (e.g., bench press throw) or activities (e.g., shot put). Second, the load we chose (i.e., 85% 1RM) is likely not optimal for improving muscular power given that lower loads have been shown to be more superior (25). Third, the cohort of recruited subjects had a minimum of only 6 months of resistance training experience. Consequently, our findings cannot be generalized to other populations including elderly and elite athletes. Fourth, there was a difference in rest distribution between groups with the CLUS group accumulating 17 minutes of rest, whereas the TRAD group accumulated 15 minutes of rest. As such, this difference in rest may have influenced the results of this study (e.g., greater training stimulus for the TRAD-set group due to performing similar work in less time). Finally, we observed a heterogeneous sample of men and women and cannot rule out that differences in individual responses to high-load resistance training may have affected the findings. Furthermore, given that there was a total of 21 subjects recruited with 9 women, an analysis using sex as a between-subject factor could not be performed because of the lack of statistical power.

In conclusion, our results indicate that CLUS- and TRAD-set structures lead to similar effects in movement velocity and muscular power across a variety of relative loads when using high-load resistance training. This finding was consistent when power was expressed relative to body mass, indicating that body mass did not contribute to this outcome. Practically, this study shows that there may be declines in movement velocity at a given relative load after high-load resistance training and that this occurs regardless of set structure. Finally, this study demonstrates that an increase in power output after high-load resistance training is likely to be driven by increases in muscular strength, independent of the set structure used during training.

Practical Applications

When training with high loads using volume-equated conditions, CLUS- and TRAD-set structures likely produce similar adaptations in muscular power and barbell velocity. However, CLUS-set structures can be used to reduce the fatigue experienced during training which may facilitate the recovery process for subsequent training sessions or limit fatigue before competitions. Coaches should be aware that, after high-load training blocks, barbell velocity may decrease at particular relative loads regardless of set structure used during training. In addition, fatigue-induced decreases in barbell velocity and power output do not seem to alter the subsequent adaptation in these variables after a high-load training block; however, if appropriate equipment is available, coaches can use barbell velocity maintenance during training to objectively monitor the fatigue of their athletes. Finally, in intermediately resistance-trained individuals who routinely perform the bench press, increases in muscular strength may be the primary driver of muscular power development after a high-load training block, regardless of set structure. Coaches can, therefore, use either set structure for the development of muscular power as part of an athlete's training schedule when high loads are used.

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