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Cluster Set Loading in the Back Squat: Kinetic and Kinematic Implications

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[1]Department of Sport, Exercise, Recreation, and Kinesiology, Center of Excellence for Sport Science and Coach Education, East Tennessee State University, Johnson City, Tennessee; [2]Department of Exercise Science and Health Education, LaGrange College, LaGrange, Georgia; and [3]Department of Physical Therapy and Human Movement Science, Sacred Heart University, Fairfield, Connecticut

Abstract

Wetmore, A, Wagle, JP, Sams, ML, Taber, CB, DeWeese, BH, Sato, K, and Stone, MH. Cluster set loading in the back squat: Kinetic and kinematic implications. *J Strength Cond Res* XX(X): 000–000, 2018—As athletes become well trained, they require greater stimuli and variation to force adaptation. One means of adding additional variation is the use of cluster loading. Cluster loading involves introducing interrepetition rest during a set, which in theory may allow athletes to train at higher absolute intensities for the same volume. The purpose of this study was to investigate the kinetic and kinematic implications of cluster loading as a resistance training programming tactic compared with traditional loading (TL). Eleven resistance-trained men (age = 26.75 ± 3.98 years, height = 181.36 ± 5.96 cm, body mass = 89.83 ± 10.66 kg, and relative squat strength = 1.84 ± 0.34) were recruited for this study. Each subject completed 2 testing sessions consisting of 3 sets of 5 back squats at 80% of their 1 repetition maximum with 3 minutes of interset rest. Cluster loading included 30 seconds of interrepetition rest with 3 minutes of interset rest. All testing was performed on dual-force plates sampling at 1,000 Hz, and the barbell was connected to 4 linear position transducers sampling at 1,000 Hz. Both conditions had similar values for peak force, concentric average force, and eccentric average force ($p = 0.25$, effect size (ES) = 0.09, $p = 0.25$, ES = 0.09, and $p = 0.60$, ES = 0.04, respectively). Cluster loading had significantly higher peak power (PP) ($p < 0.001$, ES = 0.77), peak and average velocities ($p < 0.001$, ES = 0.77, and $p < 0.001$, ES = 0.81, respectively), lower times to PP and velocity ($p < 0.001$, ES = −0.68, and $p < 0.001$, ES = −0.68, respectively) as well as greater maintenance of time to PP ($p < 0.001$, ES = 1.57). These results suggest that cluster loading may be superior to TL when maintaining power output and time point variables is the desired outcome of training.

Key Words training, rest, strength and conditioning, performance

Introduction

Over the past several years, new advanced training (AT) methods have been proposed. These AT include accentuated eccentric loading, contrast sets, complex sets, and cluster sets (CS). Cluster sets use short rest periods between repetitions as well as typical rest periods between sets (10,11). According to the specific adaptation to imposed demands (SAID) principle, changing variables within the application of an exercise elicits a specific response and subsequent adaptation, given adequate recovery is provided (32). Thus, intraset rest theoretically could allow CS to induce greater adaptations to training by allowing for heavier loading at the same training volume load (2,28), and potentiate explosiveness and power adaptations (13) by maintenance of forces (15,28), velocity (V) (12,15,17,28,34,35), or power (P) (12,15,19,20,25,27–29,34,35) at a given load when compared to traditional resistance training protocols (TP). Cluster set training could be useful for a variety of purposes such as enhancing the training effect by offering a greater stimulus or varying the stimulus to promote further adaptation. For example, training over a few years with little variation, such as can occur with maintaining TP, can limit gains and cause stagnation (4,32). Introduction of CS could produce an adaptive stimulus allowing for further gains in strength, RFD etc. During peaking phases aimed at improving power, CS training could enhance power output. Thus, CS training could be valuable for several aspects of the training process and possibly promote superior gains in strength and power when used appropriately.

Traditional loading (TL) schemes are believed to enhance adaptation, at least partly through acute fatigue. Acute fatigue could enhance motor unit recruitment (19), and

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Table 1. Back squat warm-up.*

Sets × repetitions × intensity (% 1RM)	Rest interval (min)
1 × 5 × 30%	1
1 × 3 × 50%	1
1 × 2 × 70%	2
1 × 1 × 80%	3
1 × 1 × 90%	3
1RM attempts	3

*1RM = 1 repetition maximum.

increase muscle (and whole body) metabolism and metabolite production (5,6,8,9,17,18,28,29,32), both of which may enhance adaptation to training (32). However, fatigue and increased production of metabolites as a primary stimulus for increased strength and power have both been questioned (3,5). Folland et al. (5) found that higher levels of training-induced fatigue (4 × 10 to failure) did not provide additional benefits compared to a low fatigue protocol (40 × 1) with 30 seconds of interrepetition rest designed to minimize metabolic accumulation. In addition, Folland et al. noted a tendency toward greater high-velocity gains in the low-fatigue protocol, suggesting that velocity and perhaps power would be higher with greater interrepetition rest. Indeed, further study on CS has demonstrated increased, or maintained force, rate of force development (RFD), velocity, and power for CS compared to TP (2,10,12,13,15,17,19,20,25,26,28,29,34,35).

Although CS protocols have been previously investigated, there are few studies describing both kinetic and kinematic characteristics and there are a number of limitations in these studies. A number of intraset rest periods and exercises have been used (2,4,5,6,10–15,17–22,25–29,34,35). These studies have demonstrated varying results due to the variety of protocols used. Many of the existing studies investigated CS using machines, which could alter normal technique and may not be indicative of a typical athletic setting in which CS would be logically used. Studies (4,8,9,26,27,29) used untrained subjects, which also may limit generalizability to trained populations. In addition, most studies used only one type of instrumentation or used solely kinetic or kinematic data to study CS, which may have created errors in calculation of variables, especially power. For example, Cormie et al. (1) indicate that using only kinetic data (e.g., force plate) may result in underestimating power, whereas relying solely on kinematic data (e.g., potentiometers) can result in overestimation. Combining both kinetic and kinematic data seems to be superior when investigating force and related variables such as RFD, velocity, and power (1).

The back squat is a commonly performed exercise, particularly in athletic settings. To the best of the authors' knowledge, only 2 previous studies have used a combination of kinetic and kinematic data to study the squat in previously trained subjects using CS (34,35). The results indicate that CS can enhance maintenance of force-related variables compared to TP. Due to the lack of in-depth studies investigating CS, more research is warranted. The purpose of this study is to compare CS and TP training schemes in well-trained subjects. Both kinetic and kinematic collected data were used to investigate the effects of CS as a programming tactic.

Methods

Experimental Approach to the Problem

The barbell back squat was chosen for this study because it is a widely used exercise in strength and conditioning and has similar biomechanical and neuromuscular characteristics to a variety of sporting activities (8,27,35). All subjects completed 1 pretesting session and 2 experimental testing sessions. During the pretesting session, subjects were tested on their 1 repetition maximum (RM) in the back squat to establish experimental loads. Three days separated 1RM testing and experimental conditions. The cluster loading and TL experimental conditions were randomly assigned, with 7 days separating the first and second testing session. Each experimental testing session was completed at the same time of day. A within-subject design was used to test the effect of rest distribution on kinetic and kinematic performance variables.

Subjects

Eleven male subjects (age = 26.1 ± 4.1 years, range = 22–35 yrs, height = 183.5 ± 4.3 cm, body mass = 92.5 ± 10.5 kg, and back squat to body mass ratio = 1.8 ± 0.3, presented as

Table 2. Intraclass correlation coefficient.*

	Load condition	
	TL	CS
PF	0.97	0.97
AF	1.00	1.00
PP	0.96	0.98
AP	0.98	0.89
TW	0.99	0.98
PV	0.95	0.95
AV	0.95	0.65
TTPP	0.94	0.68
TTPV	0.94	0.69

*TL = traditional loading; CS = cluster sets; PF = peak force; AF = average force; PP = peak power; AP = average power; TW = total work; PV = peak velocity; AV = average velocity; TTPP = time to peak power; TTPV = time to peak velocity.

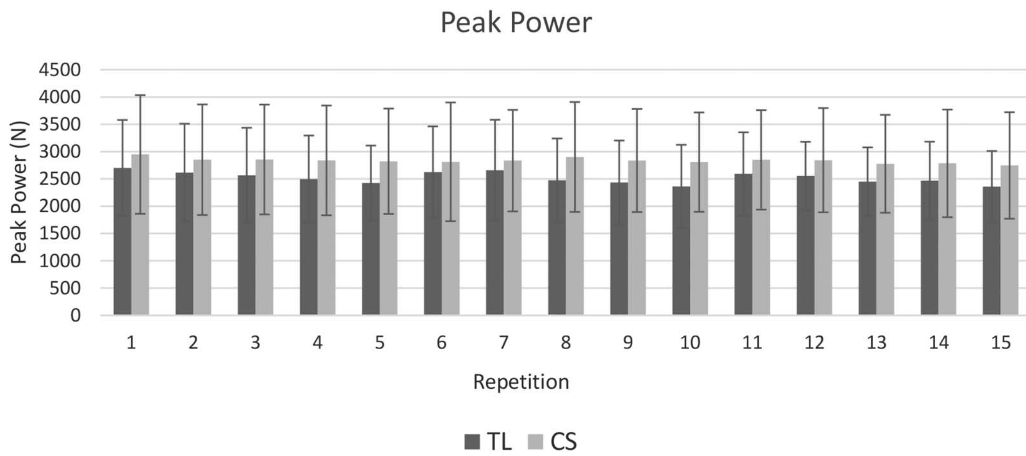

Figure 1. Peak power changes across 3 sets. TL = traditional loading; CS = cluster sets.

mean ± *SD*) were recruited for this study. All subjects were required to have at least 1 year of resistance training experience with the back squat, be able to squat at least 1.3× their body weight, and have no major injuries within the previous 3 months. This study was approved by the institutional review board of East Tennessee State University. After explaining the risks and benefits of the study, all subjects signed informed consent documents before participation in accordance with the institutional review board of the university.

Procedures

Body Composition. Body composition was estimated by a certified ISAK anthropometrist using skinfolds and Harpenden skinfold calipers (Baty International, West Sussex, United Kingdom). The skinfold sites used were: subscapular, triceps, chest, midaxillary, abdomen, iliac crest, and quadricep.

Maximum Strength Testing. Before the maximal strength testing session, each subject completed a standardized warm-up. Subjects reported self-estimated 1RMs on which warm-up repetitions were set. Warm-up repetitions began at 30% of their estimated maximum and ranged to 90% (Table 1). Subjects then performed their 1RM using a protocol modified from McBride et al. (24) and Suchomel et al. (33). The first recorded trial was at 90% of their reported 1RM and jumps were made by 2.5–5% until a maximum was reached. Full depth was defined as the subject's hip crease being below the patella and was verified by multiple certified strength and conditioning specialists.

Experimental Conditions. Subjects were randomly assigned to either the traditional set or cluster set condition at least 2 days after the 1RM testing. The opposite testing condition was separated by 1 week. Subjects were instructed to continue training as normal between conditions while restraining from any strenuous activity at least 48 hours before each testing session. All subjects completed an identical standardized dynamic warm-up before the 1RM testing. Subjects completed 3 × 5 sets at 80% of the established 1RM with 3 minutes' rest between sets in the TL condition. For the cluster condition, 30 seconds of unloaded interrepetition rest was given with 3 minutes' interset rest. Interrepetition rest intervals began once the barbell was

Table 3. Full-rep kinetic variables.*†

	TL	CS	*p*	ES
Peak force (N)	3,002 ± 503.501	3,012 ± 464.86	0.249	0.091
Peak power (W)	2,518 ± 784.099	2,834 ± 981.664	<0.001	0.77
Total work	3,035.674 ± 523.757	3,068.183 ± 575.398	<0.001	0.279

*TL = traditional loading. CS = cluster set.
†Data are presented as mean ± *SD*.

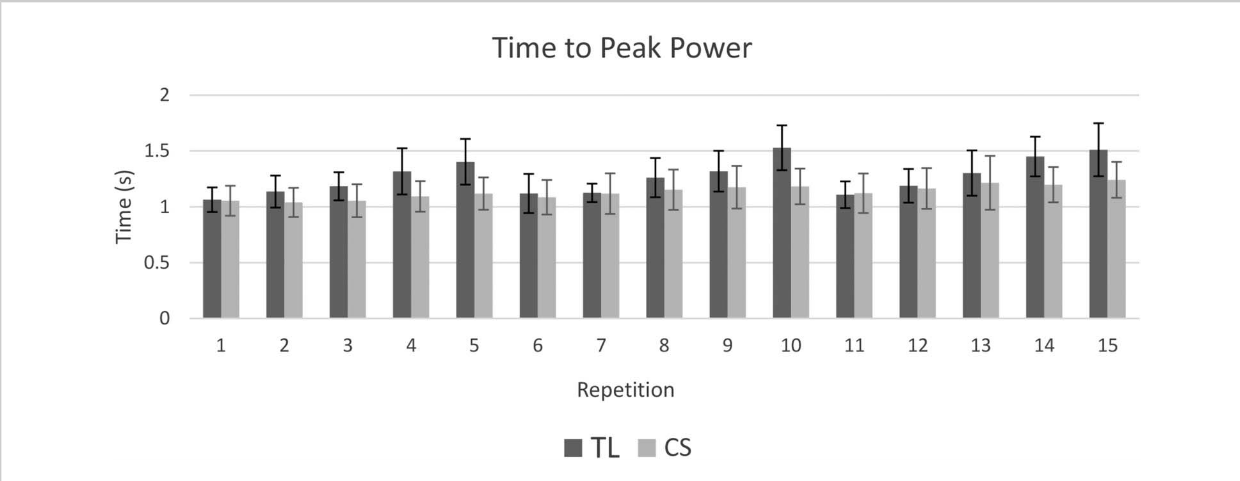

Figure 2. Changes in time to peak power across 3 sets. TL = traditional loading; CS = cluster sets.

securely racked after each repetition and ended when the barbell was unracked. Subjects were instructed to stand up as explosively as possible from the bottom of the squat. Full depth was defined as the hip crease being below the patella and was confirmed by multiple certified strength and conditioning specialists.

Instrumentation. Data were collected using dual force plates (2 × 91 cm × 45.5, 116 cm RoughDeck HP, Rice Lake, WI, USA) sampling at 1,000 Hz. The barbell was connected to 4 linear position transducers (PT101-0100-H14-1120; Celesco Measurement Specialties, Chatsworth, CA, USA) to collect kinematic data. All data were simultaneously integrated into LabVIEW (version 7.1; National Instruments).

Statistical Analyses

All data were analyzed using a custom-designed application (R Studio version 3.4.1.) Kinetic variables analyzed included: peak power (PP), peak force (PF), average power (AP), average force (AF), and total work (TW). Kinematic variables included: peak velocity (PV), average velocity (AV), time to PP (TTPP), and time to PV (TTPV). Within-subject reliability for each variable was assessed with intraclass correlation coefficients (ICCs). Interpretation of ICC was 0–0.1, 0.1–0.3, 0.3–0.5, 0.5–0.7, 0.7–0.9, and 0.9–1.0 as trivial, small, moderate, large, very large, and nearly perfect, respectively (16). Paired-sample *t*-tests were used to determine effects of condition on the above-listed variables. Cohen's *d* effect sizes (ES) were calculated for each dependent

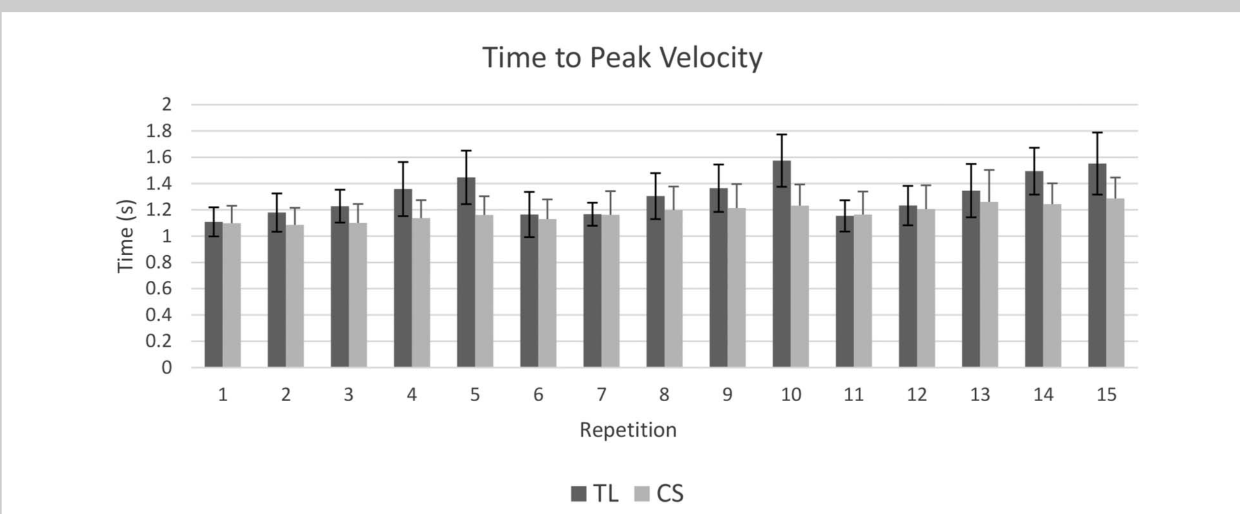

Figure 3. Changes in time to peak velocity across 3 sets. TL = traditional loading; CS = cluster sets.

TABLE 4. Kinematic variables.*†

	TL	CS	p	ES
Concentric peak velocity ($m \cdot s^{-1}$)	1.013 ± 0.175	1.106 ± 0.217	<0.001	0.767
Concentric average velocity ($m \cdot s^{-1}$)	0.489 ± 0.071	0.541 ± 0.072	<0.001	0.805
Concentric peak acceleration ($m \cdot s^{-2}$)	4.292 ± 1.503	4.421 ± 1.262	0.03	0.172
Concentric average acceleration ($m \cdot s^{-2}$)	−0.006 ± 0.002	−0.007 ± 0.003	0.002	0.241
Time to peak power (s)	1.267 ± 0.226	1.134 ± 0.178	<0.001	0.682
Time to peak velocity (s)	1.311 ± 0.225	1.178 ± 0.177	<0.001	0.684

*TL = traditional loading; CS = cluster sets.
†Data are presented as mean ± *SD*.

variable to determine the magnitude and potential meaningfulness of the differences between dependent variables across load conditions. For practical significance, effect sizes were interpreted with magnitude thresholds of 0–0.2, 0.2–0.6, 0.6–1.2, 1.2–2.0, and 2.0 and above as trivial, small, moderate, large, and very large, respectively (16). Percent changes were calculated as the change in value from repetition 1 to repetition 5 of each set and were averaged across all subjects. Statistical analysis was performed using a statistic software package (JASP version 0.8.2.0). Significance was defined as an alpha level of $p \leq 0.05$.

RESULTS

Kinetic Variables

There were no significant differences across all sets in PF ($p = 0.25$, ES = 0.09) or AF ($p = 0.25$, ES = 0.09) between conditions. Cluster loading conditions did have statistically higher TW across all sets compared with TL conditions ($p < 0.001$, ES = 0.28). In addition, cluster loading had a very large effect on PP ($p < 0.001$, ES = 0.77). Kinetic results are shown in Table 3. Traditional loading had statistically larger PP losses across all sets compared to cluster loading ($p = 0.005$, ES = 0.52) with average losses of 8.5, 9.3, and 8.3% compared to 3.3, +3.0, and 4.1% across sets 1, 2, and 3, respectively. Peak power changes across all 3 sets are shown seen in Figure 1.

Kinematic Variables

Cluster loading displayed statistically higher PV ($p < 0.001$, ES = 0.77) and AV ($p < 0.001$, ES = 0.81). In addition, cluster loading had statistically lower TTPP ($p < 0.001$, ES = −0.68) and TTPV ($p < 0.001$, ES = −0.68) compared to TL. Complete kinematic results are listed in Table 4. Traditional loading showed statistically greater increases in TTPP ($p < 0.001$, ES = 1.57) across all sets when compared to cluster loading with average increases of 31.6, 37.5, and 38.4% for sets 1, 2, and 3, respectively, whereas cluster loading conditions displayed only 6.5, 9.3, and 11.6% increases for sets 1, 2, and 3, respectively. Traditional loading conditions also demonstrated somewhat larger, although nonstatistically significant, increases in TTPV ($p = 0.329$, ES = 0.17) with average increases of 30.3, 35.9, and 36.5% for sets 1, 2, and 3, respectively, whereas cluster loading showed only 6.2, 9.2, and 11.4% increases for sets 1, 2, and 3, respectively. Changes in TTPP and TTPV are shown in Figures 2 and 3, respectively.

DISCUSSION

This study is only the third study to the best of the authors' knowledge that has investigated both kinetic and kinematic variables during cluster loading of the barbell back squat (34,35). Cormie et al. (1) suggest using only kinetic data may underestimate power output, whereas relying on kinematic data may result in overestimation in the back squat, power clean, and jump squat. Therefore, a combination of both kinetic and kinematic data was used to better estimate power outputs. In addition, many previous studies have used machines for testing (2,17,18,22,28–30). However, this may cause alterations in exercise technique and may not accurately reflect how most athletic populations train.

The results of this study support the hypothesis that cluster set loading would produce higher PP outputs, AP outputs, and velocities when compared to TL. Tufano et al. (34) found similar results with CS showing greater PV, mean velocity, PP, and mean power compared to TL. Because of the effect on power, CS may prove to be a valuable tool to enhance power, particularly during the later stages of a sequential training plan that emphasizes power production (3,32). Although evidence has consistently shown that stronger athletes are more powerful then weaker athletes (32,33), the inclusion of CS once the focus of training has shifted toward power development warrants consideration.

This leads us to consider what mechanism allows for regeneration of power with interset rest. It has been suggested that CS allow for partial or complete regeneration of phosphocreatine (PCr) to better maintain power output (8–10). This is supported by the finding of Matuszak et al. (21) that very short rest intervals as low as 1 minute are sufficient to repeat 1RM attempts. It is commonly known that high-intensity exercise relies on ATP as its main energy source. However, these energy stores are limited and may be depleted during resistance training. PCr helps to sustain this energy system but is also limited and may be depleted. Therefore, it is possible that interset rest may allow for partial replenishment of PCr, which is a more efficient energy source and may allow for higher power outputs. It has also been reported that lactate values are higher for TL than for CS, suggesting a reliance on anaerobic glycolysis for energy (2,6,29). Gorostiaga also reported higher reliance on lactate during the last 5 repetitions in a set of 10 (8). These data support the claim that CS would allow for less metabolic disturbance than TL.

Cluster set loading may provide beneficial training adaptations, especially for athletic populations. The results of this study and others suggest that cluster set loading consistently demonstrates greater PP and AP outputs when compared to TL. Although these findings are acute, chronic adaptations to cluster loading have been previously investigated (26). Morales-Artacho et al. (26) showed 3 weeks of cluster training in the countermovement jump caused greater adaptations in velocity and power. In addition, athletes must be sure to maximize movement intent when trying to stimulate beneficial training adaptations (7). González-Badillo et al. (7) showed greater gains in 1RM and AV in the bench press when training with maximal intent. González-Badillo et al. (7) also showed training with maximal intent may have caused beneficial changes in myosin heavy chain isoforms, excitability, firing rate, neural drive etc., all of which support the development of power. Finally, because many sports are time-limited (e.g., ground contact times in sprinting etc.), TTPP and TTPV are important to consider. Because of their greater maintenance of both TTPP and TTPV, CS may allow athletes to train in a more explosive manner for the entirety of the set. As mentioned earlier, this may also lend support for the inclusion of traditional sets earlier in a training year and CS later in a sequential training year. Traditional sets cause athletes to spend more time accelerating the bar, as noted in their longer TTPP and TTPV. This would seem to support the goals of strength endurance and general strength development. As you approach the later stages of a periodized model, shorter TTPP and TTPV are desired as the emphasis of training has shifted toward speed-strength development.

One limitation of the current study is that only one repetition scheme and one interrepetition rest interval were investigated. Many possible configurations of CS can be used. Others have previously investigated CS of different configurations but used different rest intervals (2,4,6,10–16,21,27). Additionally, it has been shown that exercise intensity has an effect on power outputs (3). Future investigation should be performed to determine the optimal set and rest interval configurations as well as exercise intensities to maximize training adaptations. Additionally, only one intensity was used in this study. It has been shown that exercise intensity affects power output (3). Future studies should consider the effects of CS on a variety of intensities.

Practical Applications

This study provides insight into a means of manipulating training variables to achieve the desired adaptations to training. In keeping with the principle of specificity, coaches wanting to maximize power should use programming tactics that emphasize power output. Cluster sets may provide a means of developing strength while maximizing power output by using greater absolute loads for the same volume as TL. This study demonstrates that cluster set loading maximizes power output through greater velocity both within and across sets. Therefore, CS may provide a means of directing training toward greater power development. Coaches may consider including CS during training phases in which power is the desired training goal.

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