Accentuated Eccentric Loading and Cluster Set Configurations in the Back Squat: A Kinetic and Kinematic Analysis

John P. Wagle,[1] Aaron J. Cunanan,[1] Kevin M. Carroll,[1] Matt L. Sams,[2] Alexander Wetmore,[1] Garett E. Bingham,[1] Christopher B. Taber,[3] Brad H. DeWeese,[1] Kimitake Sato,[1] Charles A. Stuart,[4] and Michael H. Stone[1]

[1]*Center of Excellence for Sport Science and Coach Education, Department of Sport, Exercise, Recreation, and Kinesiology, East Tennessee State University, Johnson City, Tennessee;* [2]*Department of Exercise Science and Health Education, LaGrange College, LaGrange, Georgia;* [3]*Department of Physical Therapy and Human Movement Science, Sacred Heart University, Fairfield, Connecticut; and* [4]*Department of Internal Medicine, Quillen College of Medicine, East Tennessee State University, Johnson, City, Tennessee*

Downloaded from https://journals.lww.com/nsca-jscr by BhDMf5ePHKav1zEoum1tQfN4a+kJLhEZgbsIHo4XMi0hCywCX1AWnYQp/IlQrHD3wXX04VDhDA6621W6L/9AGRkOUTKGUVTPVDJ4vGB56TmY= on 06/27/2018

Abstract

Wagle, JP, Cunanan, AJ, Carroll, KM, Sams, ML, Wetmore, A, Bingham, GE, Taber, CB, DeWeese, BH, Sato, K, Stuart, CA, and Stone, MH. Accentuated eccentric loading and cluster set configurations in the back squat: a kinetic and kinematic analysis. *J Strength Cond Res* XX(X): 000–000, 2018—This study examined the kinetic and kinematic differences between accentuated eccentric loading (AEL) and cluster sets in trained male subjects (age = 26.1 ± 4.1 years, height = 183.5 ± 4.3 cm, body mass = 92.5 ± 10.5 kg, and back squat to body mass ratio = 1.8 ± 0.3). Four load condition sessions consisted of traditionally loaded (TL) "straight sets," TL cluster (TLC) sets, AEL cluster (AEC) sets, and AEL "straight sets" where only the first repetition had eccentric overload (AEL1). An interrepetition rest interval of 30 seconds was prescribed for both TLC and AEC. Concentric intensity for all load conditions was 80% 1 repetition maximum (1RM). Accentuated eccentric loading was applied to repetitions using weight releasers with total eccentric load equivalent to 105% of concentric 1RM. Traditionally loaded cluster had statistically greater concentric outputs than TL. Furthermore, statistically greater eccentric and concentric outputs were observed during AEC compared with TL with the exception of peak power. Statistically greater concentric characteristics were observed in TLC compared with AEL1, but statistically greater eccentric outputs were observed in AEL1. In the 2 cluster set conditions, statistically greater concentric rate of force development (RFD_{CON}) ($d = 0.470$, $p < 0.001$) and average velocity (v_{avg}) ($d = 0.560$, $p < 0.001$) in TLC compared with AEC were observed. However, statistically greater eccentric work (W_{ECC}) ($d = 2.096$, $p < 0.001$) and eccentric RFD (RFD_{ECC}) ($d = 0.424$, $p < 0.001$) were observed in AEC compared with TLC. Overall, eccentric overload demonstrated efficacy as a means of increasing eccentric work and RFD, but not as a means of potentiating concentric output. Finally, interrepetition rest seems to have the largest influence on concentric power output and RFD.

Key Words resistance training, eccentric overload, power, programming

Introduction

Coaches aim to leverage the positive outcomes of resistance training in the physical preparation of athletic populations. The imposed training stimuli allow for the exploitation of immediate, accumulative, and long-term delayed training effects (8,23). The favorable results from resistance training are robust, demonstrating utility in the enhancement of a multitude of athletic actions including change of direction (30), linear sprinting (1), jumping ability (25), and throwing ability (35). To effectively manage fatigue and realize performance potential, coaches make deliberate programming decisions to generate more predictable outcomes (9,10). Programming tactics, then, serve to introduce variation into a periodized training program through the manipulation of one or more training variables (e.g., volume, intensity, and density). Emphasizing the importance of training variation, Hodges et al. (20) demonstrated that a novel stimulus results in more rapid performance improvement, whereas monotonous training slows adaptation. Therefore, it is especially important that coaches

Address correspondence to John P. Wagle, johnwagle9@gmail.com.

00(00)/1–8

Journal of Strength and Conditioning Research
© 2018 National Strength and Conditioning Association

Copyright © 2018 National Strength and Conditioning Association

consider a multitude of factors to maximize preparedness and performance potential.

An increasingly popular means of providing variation within a resistance training program is manipulation of the exercise phase-specific overload. Traditional loading prescribes equivalent absolute loads for the concentric and eccentric portion of an exercise. However, skeletal muscle is capable of as much as 50% more force production during maximum eccentric muscle actions compared with concentric muscle actions (42). This disparity has led to exploration of a variety of means to apply greater loads eccentrically to exercises with a paired eccentric and concentric action (e.g., weight releasers) and has been termed accentuated eccentric loading (AEL) (39). Eccentric overload theoretically increases the active state of the muscle (24), calcium sensitivity (36), or muscle spindle excitation (37)–all of which have been previously associated with acute concentric potentiation. Previous findings report advantageous changes in jumping (32), throwing (33), and resistance training (29) performance using AEL. However, these outcomes are equivocal, likely because of the inherently sensitive nature of potentiation and high-stress nature of AEL. Therefore, the exploration of factors influencing AEL-specific alterations (e.g., concentric potentiation) could provide deterministic information to coaches who aim to use this training approach.

One aspect to consider is the inherent interrepetition rest required in most common AEL applications (e.g., replacing weight releasers on the end of a barbell). It is possible that this set configuration, commonly termed a "cluster set" (28), is at least partly responsible for the favorable observations surrounding AEL (29). The potential influence on the outcomes observed with AEL aside, cluster sets are an effective means of providing variation within a training program. Although the rationale for implementation may be context specific, interrepetition rest has demonstrated the ability to allow athletes to train at a higher overall intensity and power output because of the partial recovery provided. This could allow cluster sets to provide an advantageous stimulus when training emphasizes absolute strength or peak power (PP) production. Potentiating effects seem to be most effective when used by highly trained individuals (5), which further support the possible use of cluster sets as a means of variation during later stages of a periodized plan (17). Furthermore, lower metabolite accumulations have been observed using cluster sets (15), which may alter the recovery-adaptation relationship associated with a particular work load and provide unique advantages during peaking. To properly administer such a strategy to the benefit of the athlete, the coach must possess an intimate knowledge of the training process, the acute effects of programming tactics, and their potential ramifications for chronic adaptation.

The purpose of the current investigation was to explore the kinetic and kinematic differences between AEL and cluster sets. Specifically, this study sought to compare the factors associated with enhanced interrepetition performance when using either of these prescriptions. Using the back squat, this study aimed to determine (a) the effects of eccentric overload on eccentric and concentric characteristics, (b) the effects of interrepetition rest on eccentric and concentric characteristics, and (c) how interrepetition rest may influence the responses to eccentric overload.

Methods

Experimental Approach to the Problem

To compare the kinetic and kinematic differences between AEL and cluster set configurations in the back squat, subjects were asked to complete testing protocols on five separate occasions. Back squat 1RM and three sets of five repetitions of four different experimental conditions were performed in separate testing sessions. Each repetition was performed on dual force platforms affixed with linear position transducers to assess phase-specific kinetic and kinematic characteristics of each condition.

Subjects

Eleven recreationally resistance-trained men (mean ± *SD*; age = 26.1 ± 4.1 years, height = 183.5 ± 4.3 cm, body mass = 92.5 ± 10.5 kg, and back squat to body mass ratio = 1.8 ± 0.3) volunteered for the current investigation. Subjects were required to have spent at least the past year on a weekly resistance training program that included back squats. All subjects' hydration status (urinary specific gravity) was determined before any data collection using a refractometer (Atago, Tokyo, Japan) to ensure that hydration status would not influence the results (4). All subjects read and signed written informed consent, and the procedures were approved by East Tennessee State University's Institutional Review Board.

Procedures

Dynamic strength was measured using a 1 repetition maximum (1RM) back squat, and the 1RM load was used to set the load for the experimental conditions. Dynamic strength testing was completed after 48 hours of rest to ensure that subjects were adequately recovered (2). Before testing, each subject performed a general dynamic warm-up.

After the general warm-up, bar and safety bar heights in the squat rack were adjusted as needed to best accommodate each subject. Subjects warmed up with progressively heavier loads of 30, 50, 70, 80, and 90% of their self-reported 1RM before maximal attempts. Each subject attained their back squat 1RM by attempting progressively heavier loads until they could not complete a successful repetition. For a repetition to be considered successful, the subject's hip crease must have been below the patella at the bottom of the descent during the back squat and was verified by multiple certified strength and conditioning coaches.

Experimental back squat sessions commenced at least 48 hours after participants completed 1RM testing. Experimental sessions were completed in predetermined

Copyright © 2018 National Strength and Conditioning Association

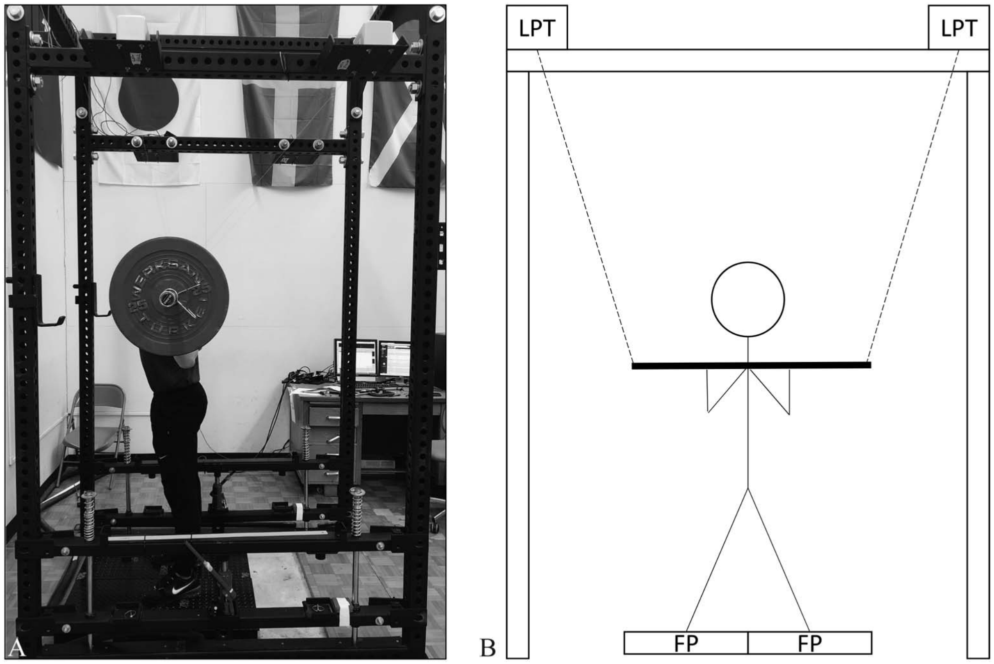

Figure 1. Custom-built rack (A) image from the lateral view and (B) schematic representation from the posterior view. LPT = linear position transducer; FP = force plate.

random order using an online randomization tool. Each session was separated by 7 days and executed at the same time of day for each subject. Between sessions, subjects could engage in training typical for their respective routines but refrained from training of any kind 48 hours before any data collection. All load conditions underwent identical data collection procedures. The general and specific warm-up was identical to that used in dynamic strength testing. Subjects completed 3 sets of 5 repetitions of the barbell back squat for the prescribed condition, each separated by 3 minutes of seated rest. Concentric intensity for all load conditions was 80% 1RM. Accentuated eccentric loading was applied to repetitions using weight releasers (Monster Grips, Columbus, OH, USA) with total eccentric load equivalent to 105% of concentric 1RM. Weight releasers were adjusted for height based on the lowest descent point in each subject's back squat technique (29). Weight releasers, because of the angle of the hanging base, are designed to release from the barbell at the bottom of the back squat, meaning that the eccentric portion of the movement is overloaded in comparison to the concentric (11,40).

Four loading conditions were used to better understand the uniqueness of AEL and cluster set configurations. Traditionally loaded (TL) "straight sets" were completed with no interrepetition rest and represented training most characteristic to that implemented with athletic populations. Subjects completed each of the 5 repetitions per set consecutively. No more than 3 seconds were allowed between repetitions, and the barbell remained placed on the participants' upper trapezius

Table 1. Intraclass correlation coefficient (ICC) to determine within-subject reliability.*

	Load condition			
	TL	TLC	AEL1	AEC
PP	0.98	0.99	0.96	0.98
W_{ECC}	1.00	1.00	1.00	0.99
W_{CON}	1.00	1.00	0.99	0.99
RFD_{ECC}	0.96	0.92	0.94	0.80
RFD_{CON}	0.97	0.85	0.90	0.98
v_{avg}	0.91	0.96	0.87	0.90

*TL = traditionally loaded straight sets; TLC = traditionally loaded cluster sets; AEL1 = accentuated eccentric loaded straight sets where only first repetition had eccentric overload applied; AEC = accentuated eccentric loaded cluster sets where each repetition had eccentric overload applied; PP = peak power; W_{ECC} = eccentric work; W_{CON} = concentric work; RFD_{ECC} = eccentric rate of force development; RFD_{CON} = concentric rate of force development; v_{avg} = average concentric velocity.

Copyright © 2018 National Strength and Conditioning Association

Table 2. Descriptive statistics using mean ± *SD* (coefficient of variation).*

Variable	Load condition			
	TL	TLC	AEL1	AEC
PP (W)	2,526.10 ± 786.41 (7.12%)	2,836.39 ± 993.46 (4.69%)	2,546.92 ± 857.03 (7.36%)	2,660.36 ± 819.61 (9.18%)
W_{ECC} (N·m)	1,483.60 ± 253.92 (1.51%)	1,479.41 ± 272.80 (1.49%)	1,502.69 ± 253.97 (4.64%)	1,627.54 ± 267.56 (2.24%)
W_{CON} (N·m)	1,581.67 ± 287.94 (1.70%)	1,622.39 ± 329.97 (1.77%)	1,586.67 ± 305.73 (2.31%)	1,604.31 ± 284.03 (2.64%)
RFD_{ECC} ($N \cdot s^{-1}$)	2,719.97 ± 1,259.78 (19.87%)	2,595.35 ± 1,189.66 (19.84%)	2,857.69 ± 1,477.50 (40.94%)	3,348.43 ± 1,437.19 (33.19%)
RFD_{CON} ($N \cdot s^{-1}$)	1,486.16 ± 855.34 (19.14%)	1,867.94 ± 876.51 (17.51%)	1,480.92 ± 859.99 (21.58%)	1,616.77 ± 942.67 (25.37%)
v_{avg} ($m \cdot s^{-1}$)	0.49 ± 0.07 (10.42%)	0.55 ± 0.07 (5.48%)	0.49 ± 0.09 (12.37%)	0.51 ± 0.08 (9.53%)

*TL = traditionally loaded straight sets; TLC = traditionally loaded cluster sets; AEL1 = accentuated eccentric loaded straight sets where only first repetition had eccentric overload applied; AEC = accentuated eccentric loaded cluster sets where each repetition had eccentric overload applied; PP = peak power; W_{ECC} = eccentric work; W_{CON} = concentric work; RFD_{ECC} = eccentric rate of force development; RFD_{CON} = concentric rate of force development; v_{avg} = average concentric velocity.

between repetitions. Two load conditions allowed for interrepetition rest, which is the basis for a cluster set (17). Traditionally loaded cluster sets were completed with identical procedures to TL, except 30 seconds of interrepetition standing rest was prescribed where the subjects placed the barbell on the safety hooks of the squat rack between repetitions. During the AEL cluster (AEC) set condition session, all 5 repetitions of the back squat were completed with eccentric overload with otherwise identical procedures to those of TL cluster (TLC) sets. After unracking the barbell from the safety hooks, the weight releasers were reattached to the barbell by 2 coaches. The fourth load condition aimed to examine the effects of AEL without the effects of interrepetition rest. The AEL "straight set" condition (AEL1) added an eccentric overload to the first repetition of each set only. Subsequent repetitions were executed without eccentric overload and with procedures identical to TL.

Data were collected using a dual force plate design (2 × 91 × 45.5 cm force plates; Rough Deck HP; Rice Lake Weighing Systems, Rice Lake, WI, USA) inside a custom-built rack (Sorinex Exercise Equipment, Lexington, SC, USA) with data sampled at 1,000 Hz. Four linear position transducers (PT101-0100-H14-1120; Celesco Measurement Specalties, Chatsworth, CA, USA) were attached to the top of the custom-built rack (Figure 1), and recoil wires were attached to the each of the ends of the barbell just inside where the plates were loaded (6). The linear position transducers were synchronized with the force plates using a custom LabVIEW (version 7.1; National Instruments) program. Data were processed using RStudio (version 1.0.153; RStudio, Inc., Boston, MA, USA). To account for and diminish noise, a digital Butterworth second-order low-pass filter with a 10 Hz cutoff frequency determined through residual analysis was applied. Eccentric and concentric phases were confirmed by the displacement values obtained from the linear position transducers. Peak power, eccentric work (W_{ECC}), concentric work (W_{CON}), eccentric rate of force development (RFD_{ECC}), concentric RFD (RFD_{CON}), and concentric average velocity (v_{avg}) were assessed for each load condition. Eccentric RFD (RFD_{ECC}) was calculated as the slope between eccentric peak force and the force value 250 ms before eccentric peak force (34). The time point of 250 ms was chosen to reflect the upper limit of time in which stored eccentric energy may be used to enhance the subsequent concentric action rather than dissipated as heat (38). Concentric RFD (RFD_{CON}) was calculated using the concentric peak force and the force value 250 ms before concentric peak force (34).

Statistical Analyses

Descriptive statistics including mean and *SD* were calculated. Within-subject reliability for each variable was assessed using intraclass correlation coefficients (ICCs) (22).

Copyright © 2018 National Strength and Conditioning Association

TABLE 3. Post hoc comparisons and effect sizes with practical interpretations (21).*

Variable	Load condition	Comparator	Cohen's *d*		p_{Holm}
PP	AEL1	TL	0.018	Trivial	0.819
		TLC	−0.342	Small	<0.001†
		AEC	−0.086	Trivial	0.619
	TLC	TL	0.268	Small	0.004†
		AEC	0.125	Trivial	0.457
	AEC	TL	0.100	Trivial	0.619
W_{ECC}	AEL1	TL	0.211	Small	0.024†
		TLC	0.255	Small	0.008†
		AEC	−1.313	Large	<0.001†
	TLC	TL	−0.088	Trivial	0.292
		AEC	−2.096	Very large	<0.001†
	AEC	TL	1.786	Large	<0.001†
W_{CON}	AEL1	TL	0.063	Trivial	0.448
		TLC	−0.380	Small	<0.001†
		AEC	−0.186	Small	0.080
	TLC	TL	0.500	Moderate	<0.001†
		AEC	0.161	Trivial	0.108
	AEC	TL	0.225	Small	0.030†
RFD_{ECC}	AEL1	TL	0.099	Trivial	0.259
		TLC	0.224	Small	<0.001†
		AEC	−0.271	Small	0.006†
	TLC	TL	−0.127	Trivial	0.259
		AEC	−0.424	Small	<0.001†
	AEC	TL	0.342	Small	<0.001†
RFD_{CON}	AEL1	TL	−0.013	Trivial	0.871
		TLC	−0.886	Moderate	<0.001†
		AEC	−0.262	Small	0.006†
	TLC	TL	0.890	Large	<0.001†
		AEC	0.470	Small	<0.001†
	AEC	TL	0.232	Small	0.012†
v_{avg}	AEL1	TL	−0.072	Trivial	0.389
		TLC	−0.954	Moderate	<0.001†
		AEC	−0.252	Small	0.008†
	TLC	TL	1.035	Moderate	<0.001†
		AEC	0.560	Small	<0.001†
	AEC	TL	0.201	Small	0.034†

*PP = peak power; AEL1 = accentuated eccentric loaded straight sets where only first repetition had eccentric overload applied; TL = traditionally loaded straight sets; TLC = traditionally loaded cluster sets; AEC = accentuated eccentric loaded cluster sets where each repetition had eccentric overload applied; W_{ECC} = eccentric work; W_{CON} = concentric work; RFD_{ECC} = eccentric rate of force development; RFD_{CON} = concentric rate of force development; v_{avg} = average concentric velocity.

†Statistically significant relationship at a critical alpha of 0.05.

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 (21). Coefficient of variation (CV) was calculated for each load condition. One-way within-subject analysis of variance was performed against the independent variable of load condition for each dependent variable. Data were screened for sphericity using Mauchly's test. If the assumption of sphericity was violated, a Greenhouse-Geisser correction was performed for the dependent variable being considered before any further analysis. The critical alpha level was set at $p \leq 0.05$. If a main effect was observed, a Holm-Bonferroni post hoc comparison was performed to determine between which conditions the significance occurred and to account for family-wise error. Cohen's *d* effect sizes were calculated for each dependent variable to determine the magnitude and 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 (21). Statistical analyses were performed using JASP (version 0.8.1.2; Amsterdam, Netherlands).

RESULTS

Relative reliability of all dependent variables returned at least very large ICC values (Table 1), whereas absolute reliability

Copyright © 2018 National Strength and Conditioning Association

of the dependent variables returned CV values ranging between 1.49 and 40.94% (Table 2). There were significant between-condition main effects for PP ($p = 0.007$), W_{ECC} ($p < 0.001$), W_{CON} ($p < 0.001$), RFD_{ECC} ($p < 0.001$), RFD_{CON} ($p < 0.001$), and v_{avg} ($p < 0.001$).

Post hoc comparisons of load conditions without eccentric overload revealed that TLC had statistically greater concentric outputs than TL (Table 3). However, post hoc comparisons showed that eccentric overload during the first repetition only during a straight (AEL1) set produced statistically greater W_{ECC} ($d = 0.211$, $p = 0.024$) compared with TL.

The next post hoc comparison examined the effect of AEL on cluster sets. Statistically greater RFD_{CON} ($d = 0.470$, $p < 0.001$) and v_{avg} ($d = 0.560$, $p < 0.001$) in TLC compared with AEC were observed. However, statistically greater W_{ECC} ($d = 2.096$, $p < 0.001$) and RFD_{ECC} ($d = 0.424$, $p < 0.001$) were observed in AEC compared with TLC. No statistical differences between TLC and AEC were present in PP ($d = 0.125$, $p = 0.457$) or W_{CON} ($d = 0.161$, $p = 0.108$).

In examining the potential difference between straight sets and the combination of interrepetition rest and eccentric overload, post hoc comparisons showed statistically greater W_{ECC} ($d = 1.786$, $p < 0.001$), W_{CON} ($d = 0.225$, $p = 0.030$), RFD_{ECC} ($d = 0.342$, $p < 0.001$), RFD_{CON} ($d = 0.232$, $p = 0.01$), and v_{avg} ($d = 0.201$, $p = 0.034$) during AEC compared with TL. Statistically greater concentric characteristics were observed in TLC compared with AEL1; however, statistically greater eccentric outputs were observed in AEL1 (Table 3). The final post hoc comparison examined the difference between the 2 load conditions that used eccentric overload, AEL1 and AEC. Statistically greater W_{ECC} ($d = 1.313$, $p < 0.001$), RFD_{ECC} ($d = 0.271$, $p = 0.006$), RFD_{CON} ($d = 0.262$, $p = 0.006$), and v_{avg} ($d = 0.252$, $p = 0.008$) were observed in AEC compared with AEL1 (Table 3).

Discussion

The purpose of this investigation was to explore the kinetic and kinematic differences between potential programming tactics in the back squat. Specifically, the authors aimed to determine (a) the effects of eccentric overload on eccentric and concentric characteristics and (b) the effects of interrepetition rest on eccentric and concentric characteristics to gain insight into the potential applications of these programming tactics in resistance training. The results of the current investigation reveal that eccentric overload significantly increases the work performed during the eccentric phase compared with TL, even when applied to only the initial repetition of a set. The results demonstrate the favorable effects of interrepetition rest interval on concentric outputs, which agrees with previous literature on cluster sets (15,19). Finally, acute potentiation of concentric outputs after application of eccentric overload was not supported.

Previous research has demonstrated the effectiveness of AEL to enhance muscle hypertrophy, particularly in the type II fibers (13,14,41). Greater mechanical tension experienced during AEL eccentrically compared with TL resistance training is a potential mechanism for this effect (12). The current investigation supports this hypothesis, as the application of eccentric overload (AEL1 and AEC) significantly increased W_{ECC} compared with traditional loading (TL and TLC). The larger summation of forces experienced during AEL may therefore provide rationale for increased mechanical tension and the previously observed alterations in muscle hypertrophy with chronic exposure to AEL (13,14,41). Even when eccentric overload was applied for a single repetition within a given set, as in AEL1, the small effect observed in W_{ECC} compared with both TL conditions may have valuable implications when chronically applied. This novel and practical loading tactic affords the coach the opportunity to maintain aspects of straight sets (e.g., metabolite accumulation) with the potential additional outcome of muscle hypertrophy because of higher absolute EL (12,15). Although beyond the scope of this investigation, future studies should explore the influence that the chronic exposure to increased eccentric work in the back squat has on changes in muscle size.

Another potential rationale for prescribing AEL as a programming tactic in resistance training is to facilitate an acute potentiating effect. Accentuated eccentric loading has been demonstrated to acutely potentiate concentric outputs in previous literature (11,29,31). However, the potentiating effects of AEL on the squat have only been recently investigated (27,29). When eccentric actions are rapid and forceful, it is possible that a greater muscle spindle activation (7), a greater stretch of the musculotendinous complex (16), or a preattachment of cross-bridges (3) occur and contribute to enhancing concentric force application. To fully exploit these potentially favorable mechanisms, a rapid eccentric action should be tightly coupled with the concentric action (38). The statistically greater RFD_{ECC} observed during AEC compared with TL conditions suggests that the eccentric action immediately preceding the concentric phase was more rapid because of the presence of overload. Considering the established relationship between eccentric RFD and concentric potentiation (26), enhanced concentric outputs would be expected. However, concentric PP, W_{CON}, RFD_{CON}, and v_{avg} were all unaffected by the inclusion of eccentric overload in the current investigation. The findings agree with Munger et al. (29) regarding 105% 1RM as an eccentric overload. Because there was no difference in concentric outputs as opposed to a detrimental result, it is possible that the eccentric loading was not substantial enough to induce potentiation. Potentiation has recently been demonstrated in the squat using greater magnitudes of eccentric overload, upward of 120% (29). However, the optimal intensity prescription and other programming decisions may be more nuanced. Acute potentiation from AEL seems to be highly individualized (31), and consideration may need to be made to both the eccentric and concentric load prescriptions (39). It is also worth noting at this point that magnitude

Copyright © 2018 National Strength and Conditioning Association

of overload prescription may be somewhat dependent on exercise selection (11,29,31,40). Ojasto and Häkkinen (31) observed force production decrements at 105, 110, and 120% 1RM eccentric overload in the bench press. The concentric prescription of 100% 1RM used by Ojasto and Häkkinen may have also contributed to the observed fatiguing effect, whereas Munger et al. used 90% 1RM in the front squat (29,31). It has also been suggested that maximal eccentric contractions could have detrimental effects on concentric outputs when coupled, albeit using isokinetic exercise (23). Nonetheless, previous work combined with the findings of the current investigation emphasizes the potentially delicate nature of balancing potentiation and fatigue when using AEL as well as the myriad of programming aspects that should be considered (29,31).

One common strategy to manage acute fatigue is to provide an athlete with interrepetition rest (15). Cluster sets have also previously demonstrated the ability to be an effective method for inducing velocity and power adaptations to specific loads (18,28). Acutely, such a tactic allows the athlete to have consistently higher power outputs while incurring less metabolic stress and fatigue (15). The results of this investigation agree with previous research, as PP, W_{CON}, RFD_{CON}, and v_{avg} were all significantly greater in TLC compared with straight set conditions. Adding eccentric overload to a cluster seems to have a trivial negative effect on PP and W_{CON} when compared with TLC. Furthermore, RFD_{CON} and v_{avg} had small effect detriments in AEC compared with TLC. These findings suggest that when the highest potential rates of movement and force application are the desired outcome, adding eccentric overload to the existing approach of interrepetition rest may be disadvantageous.

In conclusion, the results of the current investigation demonstrate that (a) the addition of eccentric overload increases the magnitude and rate of eccentric force development. (b) Although theoretically relevant for acute potentiation, AEL may be sensitive to the magnitude of overload to elicit increases in concentric outputs. (c) Our results provide strong evidence for the inclusion of interrepetition rest in producing the greatest concentric outputs, especially considering rate-related measures. Future research should investigate the role that different combinations of eccentric and concentric loading schemes have on acute potentiation to further elucidate this point. Future research should also examine the adaptations and delayed training effects associated with chronic exposure to AEL, particularly regarding strength and power athletes based on the current findings and those of previous literature.

Practical Applications

Eccentric overload demonstrated efficacy as a means of increasing eccentric work and RFD, but its efficacy in acute concentric potentiation was not supported by the current investigation. Therefore, strength and conditioning coaches may choose to implement AEL as a progression toward more rapid and forceful eccentric actions such as plyometrics or sprinting. The value of interrepetition rest on concentric output was also demonstrated in the current investigation. This finding supports previous literature of the potential utility of cluster sets as a means of increasing the overall power output of the athlete within a training session (15,19). Such a strategy may potentially be useful during tapering and peaking phases of periodized resistance training plans. Finally, the usage of interrepetition rest intervals may be programmed when the highest achievable concentric outputs are desired (e.g., PP and RFD), but may be at the expense of potential metabolic effects present when interrepetition rest is not prescribed.

References

1. Alexander, M. The relationship between muscle strength and sprint kinematics in elite sprinters. *Can J Sport Sci* 14: 148–157, 1989.
2. Bishop, PA, Jones, E, and Woods, AK. Recovery from training: A brief review: Brief review. *J Strength Cond Res* 22: 1015–1024, 2008.
3. Bobbert, MF, Gerritsen, KG, Litjens, MC, and Van Soest, AJ. Why is countermovement jump height greater than squat jump height? *Med Sci Sports Exerc* 28: 1402–1412, 1996.
4. Buford, TW, Rossi, SJ, Smith, DB, O'brien, MS, and Pickering, C. The effect of a competitive wrestling season on body weight, hydration, and muscular performance in collegiate wrestlers. *J Strength Cond Res* 20: 689, 2006.
5. Chiu, LZ, Fry, AC, Weiss, LW, Schilling, BK, Brown, LE, and Smith, SL. Postactivation potentiation response in athletic and recreationally trained individuals. *J Strength Cond Res* 17: 671–677, 2003.
6. Cormie, P, McBride, JM, and McCaulley, GO. Validation of power measurement techniques in dynamic lower body resistance exercises. *J Appl Biomech* 23: 103–118, 2007.
7. Cormie, P, McGuigan, MR, and Newton, RU. Changes in the eccentric phase contribute to improved stretch-shorten cycle performance after training. *Med Sci Sports Exerc* 42: 1731–1744, 2010.
8. Counsilman, B and Counsilman, J. The residual effects of training. *J Swim Res* 7: 5–12, 1991.
9. DeWeese, BH, Hornsby, G, Stone, M, and Stone, MH. The training process: Planning for strength–power training in track and field. Part 1: Theoretical aspects. *J Sport Health Sci* 4: 308–317, 2015.
10. DeWeese, BH, Hornsby, G, Stone, M, and Stone, MH. The training process: Planning for strength–power training in track and field. Part 2: Practical and applied aspects. *J Sport Health Sci* 4: 318–324, 2015.
11. Doan, BK, Newton, RU, Marsit, JL, Triplett-McBride, NT, Koziris, LP, Fry, AC, et al. Effects of increased eccentric loading on bench press 1RM. *J Strength Cond Res* 16: 9–13, 2002.
12. Franchi, MV, Reeves, ND, and Narici, MV. Skeletal muscle remodeling in response to eccentric vs. concentric loading: Morphological, molecular, and metabolic adaptations. *Front Physiol* 8: 447, 2017.
13. Friedmann-Bette, B, Bauer, T, Kinscherf, R, Vorwald, S, Klute, K, Bischoff, D, et al. Effects of strength training with eccentric overload on muscle adaptation in male athletes. *Eur J Appl Physiol* 108: 821–836, 2010.
14. Friedmann, B, Kinscherf, R, Vorwald, S, Muller, H, Kucera, K, Borisch, S, et al. Muscular adaptations to computer-guided strength training with eccentric overload. *Acta Physiol Scand J* 182: 77–88, 2004.

Copyright © 2018 National Strength and Conditioning Association

15. González-Hernádez, J, García-Ramos, A, Capelo-Ramírez, F, Castaño-Zambudio, A, Marquez, G, Boullosa, D, et al. Mechanical, metabolic, and perceptual acute responses to different set configurations in full squat. *J Strength Cond Res*, 2017. doi:10.1519/JSC.0000000000002117
16. Griffiths, R. Shortening of muscle fibres during stretch of the active cat medial gastrocnemius muscle: The role of tendon compliance. *J Physiol* 436: 219, 1991.
17. Haff, GG, Hobbs, RT, Haff, EE, Sands, WA, Pierce, KC, and Stone, MH. Cluster training: A novel method for introducing training program variation. *Strength Cond J* 30: 67–76, 2008.
18. Hansen, KT, Cronin, JB, Pickering, SL, and Newton, MJ. Does cluster loading enhance lower body power development in preseason preparation of elite rugby union players? *J Strength Cond Res* 25: 2118–2126, 2011.
19. Hardee, JP, Triplett, NT, Utter, AC, Zwetsloot, KA, and Mcbride, JM. Effect of interrepetition rest on power output in the power clean. *J Strength Cond Res* 26: 883–889, 2012.
20. Hodges, NJ, Hayes, S, Horn, RR, and Williams, AM. Changes in coordination, control and outcome as a result of extended practice on a novel motor skill. *Ergonomics* 48: 1672–1685, 2005.
21. Hopkins, W, Marshall, S, Batterham, A, and Hanin, J. Progressive statistics for studies in sports medicine and exercise science. *Med Sci Sports Exerc* 41: 3, 2009.
22. Hopkins, WG. Spreadsheets for analysis of validity and reliability. *Sportscience* 21, 2017. Available at http://www.sportsci.org/2015/ValidRely.htm.
23. Keogh, JW, Wilson, GJ, and Weatherby, RE. A cross-sectional comparison of different resistance training techniques in the bench press. *J Strength Cond Res* 13: 247–258, 1999.
24. Komi, PV. Physiological and biomechanical correlates of muscle function: Effects of muscle structure and stretch-shortening cycle on force and speed. *Exerc Sport Sci Rev* 12: 81–122, 1984.
25. Kraska, JM, Ramsey, MW, Haff, GG, Fethke, N, Sands, WA, Stone, ME, et al. Relationship between strength characteristics and unweighted and weighted vertical jump height. *Int J Sports Physiol Perform* 4: 461–473, 2009.
26. Kyröläinen, H and Komi, PV. The function of neuromuscular system in maximal stretch-shortening cycle exercises: Comparison between power-and endurance-trained athletes. *J Electromyogr Kinesiol* 5: 15–25, 1995.
27. MacDonald, CJ. Acute responses of muscle activation during eccentric accentuated loaded squats and normal loaded squats in collegiate weightlifters. Doctoral dissertation, East Tennessee State University, Johnson City, 2013.
28. Morales-Artacho, AJ, Padial, P, García-Ramos, A, Pérez-Castilla, A, and Feriche, B. Influence of a cluster set configuration on the adaptations to short-term power training. *J Strength Cond Res* 32: 930–937, 2018.
29. Munger, CN, Archer, DC, Leyva, WD, Wong, MA, Coburn, JW, Costa, PB, et al. Acute effects of eccentric overload on concentric front squat performance. *J Strength Cond Res* 31: 1192–1197, 2017.
30. Nimphius, S, McGuigan, MR, and Newton, RU. Changes in muscle architecture and performance during a competitive season in female softball players. *J Strength Cond Res* 26: 2655–2666, 2012.
31. Ojasto, T and Häkkinen, K. Effects of different accentuated eccentric load levels in eccentric-concentric actions on acute neuromuscular, maximal force, and power responses. *J Strength Cond Res* 23: 996–1004, 2009.
32. Sheppard, J, Newton, R, and McGuigan, M. The effect of accentuated eccentric load on jump kinetics in high-performance volleyball players. *Int J Sports Sci Coach* 2: 267–273, 2007.
33. Sheppard, JM and Young, K. Using additional eccentric loads to increase concentric performance in the bench throw. *J Strength Cond Res* 24: 2853–2856, 2010.
34. Stevenson, MW, Warpeha, JM, Dietz, CC, Giveans, RM, and Erdman, AG. Acute effects of elastic bands during the free-weight barbell back squat exercise on velocity, power, and force production. *J Strength Cond Res* 24: 2944–2954, 2010.
35. Stone, MH, Sanborn, K, O'bryant, HS, Hartman, M, Stone, ME, Proulx, C, et al. Maximum strength-power-performance relationships in collegiate throwers. *J Strength Cond Res* 17: 739–745, 2003.
36. Sweeney, H, Bowman, BF, and Stull, JT. Myosin light chain phosphorylation in vertebrate striated muscle: Regulation and function. *Am J Physiol* 264: C1085–C1095, 1993.
37. Taylor, JL, Butler, JE, and Gandevia, S. Changes in muscle afferents, motoneurons and motor drive during muscle fatigue. *Eur J Appl Physiol* 83: 106–115, 2000.
38. Vogt, M and Hoppeler, HH. Eccentric exercise: Mechanisms and effects when used as training regime or training adjunct. *J Appl Physiol* 116: 1446–1454, 2014.
39. Wagle, JP, Taber, CB, Cunanan, AJ, Bingham, GE, Carroll, KM, DeWeese, BH, et al. Accentuated eccentric loading for training and performance: A review. *Sports Med* 47: 2473–2495, 2017.
40. Walker, S, Blazevich, AJ, Haff, GG, Tufano, JJ, Newton, RU, and Hakkinen, K. Greater strength gains after training with accentuated eccentric than traditional isoinertial loads in already strength-trained men. *Front Physiol* 7: 149, 2016.
41. Walker, S, Häkkinen, K, Haff, GG, Blazevich, AJ, and Newton, RU. Acute elevations in serum hormones are attenuated after chronic training with traditional isoinertial but not accentuated eccentric loads in strength-trained men. *Physiol Rep* 5: e13241, 2017.
42. Westing, SH, Seger, JY, Karlson, E, and Ekblom, B. Eccentric and concentric torque-velocity characteristics of the quadriceps femoris in man. *Eur J Appl Physiol Occup Physiol* 58: 100–104, 1988.

Copyright © 2018 National Strength and Conditioning Association