Exploring the Utility of Performing a Down Set as a Postactivation Potentiation Strategy

Hanson Wong, Jeremy Gentles, Caleb Bazyler, and Michael Ramsey

Department of Exercise and Sport Sciences, Center of Excellence for Sport Science and Coach Education, East Tennessee State University, Johnson City, Tennessee

Abstract

Wong, H, Gentles, J, Bazyler, C, and Ramsey, M. Exploring the utility of performing a down set as a postactivation potentiation strategy. *J Strength Cond Res* 35(5): 1217–1222, 2021—The purpose of this study was to determine if successive heavy sets of back squats can augment the concentric velocity of a lighter down set performed by strength-trained men. Twelve trained men with experience in the back squat volunteered to perform a 5 repetition maximum (5RM) along with 2 separate squat sessions consisting of 3 sets of 5 repetitions with 85% of their 5RM. One condition involved performing a "down set" (DS) after the 3 working sets at 85% of 5RM equivalent to 60% of the working-set load that was also performed during the warm-up. A "No down set" condition involved performing an additional warm-up set before the working sets with 60% of the working-set load instead of the down set to determine if velocity was augmented because of postactivation potentiation in the DS condition. In both conditions, 3 minutes of rest was applied between all sets. A paired sample *t*-test was used to compare the mean concentric velocities (MCVs) of the working sets of both conditions, and a repeated measures analysis of variance was used to assess differences in MCVs between sets performed at 60% of the working-set load. Cohen's *d* effect sizes were reported for all comparisons, and the critical alpha was set at $p \leq 0.05$. No significant differences were observed in the working-set MCVs in both conditions ($p = 0.412$, $d = 0.246$) or between MCVs in the down set and equivalent warm-up set load in the DS condition ($p = 0.270$, $d = 0.002$).Although performing a down set may still be efficacious for developing power across a broad spectrum of loads, the results of this study suggest successive heavy sets of back squats do not acutely augment down set concentric velocity in strength-trained men.

Key Words: back squat, power training, concentric velocity, linear position transducer

Introduction

High levels of muscular strength and power are crucial physical characteristics impacting sport success (4,38,44,45). It is well established that heavy resistance training is required to induce the physiological and neural adaptations that augment force generation capabilities (22,31). Considering power is the product of force and velocity, strength training is an essential foundational element for long-term power development. To maximize overall power development, it is crucial to develop the ability to express high forces with greater muscle contractile velocities (21). Training approaches that only target strength or power development could limit performance in sports such as rugby and American football, which require the ability to produce high power outputs under a variety of loaded conditions (2,3,40). Thus, muscular power is typically developed by training across a broad spectrum of loads ranging from 30 to 70% of one repetition maximum (1RM) in strength exercises, using ballistic exercises and plyometrics, and training weightlifting derivatives (12,13,21).

Postactivation potentiation (PAP) is an advanced training technique used to develop power and refers to an acute performance enhancement that is influenced by muscular contractile history (10,19,27,30,32). A strength-power potentiation complex typically applies PAP by sequencing a high-force conditioning activity such as heavy sets of back squat (>85% 1RM) before performing a high-velocity movement such as a vertical jump after a rest interval (32,36). Careful manipulation of the volume, intensity, and rest interval of the conditioning exercise is necessary to minimize fatigue and improve performance in the subsequent high-velocity movement (36). In support, a meta-analysis by Seitz and Haff (32) found that using loads above 85% of 1RM (effect size [ES] = 0.41) and performing multiple sets of a conditioning activity (ES = 0.69) may be more favorable for inducing PAP. Furthermore, stronger individuals (squat 1RM/body mass ≥2.0) were able to express greater potentiation effects (ES = 0.41) than weaker individuals (squat 1RM/body mass ≤2.0) (ES = 0.32) primarily because of greater fatigue resistance.

Although high-force conditioning activities (e.g., 3 sets × 5 repetitions of back squats with 85% 1RM) have been shown to acutely enhance performance in a wide range of high-velocity movements (10,20,32,39,42), less is known about their ability to acutely improve performance in the same task using a lighter load (i.e., a down set of back squats with 60% 1RM). In this regard, down sets are performed with maximal effort after heavy working sets using 50–60% of the working-set load and are believed to provide a power-training stimulus during strength-oriented training blocks in strength-power athletes (15,26,34,35,37) by providing additional work with loads that can maximize power outputs (12,34). Accordingly, it has been postulated that heavy working sets can induce a PAP effect enabling down sets to be moved with greater velocities (29). In support, Stone et al. (36) found a significant, 5.3% increase in concentric peak velocity during a down set of midthigh pulls (1 × 5 with ~65% of the heaviest working set) compared with the same warm-up load in

Address correspondence to Hanson P. Wong, wongh1@etsu.edu.

Journal of Strength and Conditioning Research 35(5)/1217–1222

international-level USA weightlifters. Although midthigh pulls are well suited as a potentiation modality (16), the PAP effect observed by Stone et al. (36) during the down set may not apply to strength-oriented exercises such as the back squat. Accordingly, unpublished results from Carter et al. (8) showed no difference in weightlifters' concentric peak velocity between a load and repetition-matched warm-up set and down set (1 × 5 with 55% 1RM) in dead-stop squats, with 3 × 1 with 85% 1RM used as the conditioning activity before the down set. Therefore, the acute effects of high-force conditioning activities on down set performance require further investigation in other programming configurations and conditions. In addition to these conflicting findings, the velocity at which the eccentric phase is executed has been shown to affect the concentric velocity in the squat and bench press (9), which may be an important factor in modulating the expression of PAP (18). Furthermore, strength training movements involving a full stretch-shortening cycle (e.g., back squat, overhead press, and bent over rows) induce greater acute peripheral fatigue than concentric-only movements, which may hinder the expression of PAP (39). Most importantly, athletes more commonly strength train with movements involving a full stretch-shortening cycle and successive heavy sets (e.g., 3 × 5 with 85% 1RM) (15,22,25,34,35). Therefore, it is necessary to determine whether strength training movements that involve a full stretch-shortening cycle can acutely enhance down set performance. Accordingly, the purpose of this study was to determine if successive heavy sets of back squats can augment the concentric velocity of a lighter down set performed by strength-trained men. We hypothesized that there would be no increase in concentric velocity during the down sets because of accumulated fatigue from working sets.

Methods

Experimental Approach to the Problem

A counterbalanced, cross-over design was used to assess the effects of successive sets of back squats on concentric velocity during a down set. The back squat was chosen for this study because of its ubiquity in strength and conditioning programs and its biomechanical and neuromuscular specificity to a variety of sporting skills. All subjects attended a familiarization session before performing a 5RM assessment and 2 experimental testing sessions. During the familiarization session, subjects were informed of the study procedures and performed a 5RM in the back squat to determine experimental loads. After familiarization, subjects completed experimental conditions in a randomized order spaced 48–72 hours apart. To account for daily biorhythms, all conditions were tested at approximately the same time of day. All subjects were encouraged to maintain their dietary, sleeping, and drinking habits. Although all subjects were permitted to continue their routine training, no lower-body training was permitted between all scheduled testing sessions.

Subjects

Twelve trained male subjects ($n = 12$; age = 25.6 ± 5.9 years; height = 177.8 ± 7.5 cm; body mass = 91.2 ± 17.8 kg; 5RM = 130 ± 32.6 kg; estimated 1RM back squat to body mass ratio = 1.61 ± 0.25 ± *SE*) were recruited for this study. All subjects were required to (a) have at least 2 years of resistance training experience with the back squat, (b) have an estimated 1RM back squat >1.5 times their body mass, and (c) have no major injuries within the previous 3 months. After explaining the risks and benefits of the study, all subjects signed a written informed consent document before participation in accordance with the university's institutional review board. The subjects' resistance training backgrounds included weightlifting, powerlifting, and bodybuilding. Before participating in the study, the subjects received information about the study purpose and provided written informed consent. The study was approved by East Tennessee State University's Institutional Review Board for testing of human subjects.

Procedures

Five Repetition Maximum Testing. Subjects were instructed to cease training for at least 24 hours before testing. Before all sessions, subjects performed a dynamic warm-up including 25 jumping jacks, 10 leg swings each leg, 10 reverse lunges with overhead reaches each leg, 10 lateral lunges each leg, 20 step back with trunk rotations, 10 squat to toe-touches, and 10 body mass squats. Subjects completed a 5RM back squat protocol modified from Comfort and McMahon study (11). The warm-up sets followed the loading scheme described in Table 1. The first recorded trial was performed at their reported 5RM and the load was increased by 2.5–5% until a maximum was reached. Full depth was defined as the subject's hip crease being below the knees and was verified by multiple Certified Strength and Conditioning Specialists. Subjects' 5RMs were used to estimate 1RMs using the Brzycki formula to verify that they met the strength criteria (6).

Experimental Conditions. All subjects completed the same standardized dynamic warm-up as performed during 5RM testing. Subjects completed the down set (DS) and no down set (NDS) conditions in a randomized order separated by 48–72 hours depending on their schedule. Both conditions required subjects to complete 3 working sets of 5 repetitions at 85% of their 5RM with 3 minutes of rest between sets; this rest interval was maintained for warm-up sets and down sets. The configuration of the DS condition, rest intervals, and use of 85% relative intensity in both conditions was designed to replicate the exact scheme used in training scenarios (15,25,26,34,37). The DS and NDS configurations are described in Tables 2 and 3, respectively. In the NDS condition, an additional warm-up set (60% of working-set load) was performed for comparison with the DS condition. Finally, subjects were instructed to perform the eccentric portion of the squat at a self-selected pace and to move the barbell as fast as possible during the concentric phase. During the study briefing, the down set was not described as a power exercise of any sort to obviate for any potential bias from the subjects to perform the down set with more intent than the warm-up sets. If a subject believes that they are supposed to move down sets faster to obtain the desired adaptation, then this could artificially improve the outcome apart from any PAP response.

Table 1
5RM warm-up loading scheme.*

Set 1	Ten repetitions with 20 kg barbell
Set 2	Five repetitions with 50% of the estimated 5RM
Set 3	Five repetitions with 60% of the estimated 5RM
Set 4	Five repetitions with 70% of the estimated 5RM
Set 5	Three repetitions with 80% of the estimated 5RM
Set 6	Three repetitions with 90% of the estimated 5RM
Set 7	5RM attempt 1
Set 8	5RM attempt 2
Set 9	5RM attempt 3

*5RM = 5 repetition maximum.

Table 2
Down set condition loading scheme*

Set	Load
Warm-up set 1	Ten repetitions with 20 kg barbell
Warm-up set 2	Five repetitions at 40% of target for a working set
Warm-up set 3	Five repetitions at 60% of target for a working set
Working-set 1	Five repetitions at 85% of 5RM
Working-set 2	Five repetitions at 85% of 5RM
Working-set 3	Five repetitions at 85% of 5RM
Down set†	Five repetitions at 60% of target for a working set

*5RM = 5 repetition maximum.
†Signifies different set placement compared with the no down set condition.

Velocity Measurement. A Speed4Lift (Speed4Lift; Madrid, Spain) linear position transducer (LPT) was attached to each side of the barbell to collect acceleration-derived metrics through integration with a tablet (Apple iPad Air; iOS 11.4.1; Apple, Cupertino, CA) and smartphone (Apple iPhone XR; iOS 13.3.1; Apple, Cupertino, CA). When compared with a gold standard optical motion sensing system (V120: Trio, OptiTrack; NaturalPoint, Inc.), the Speed4Lift coefficient of variation (CV) was determined to be 2.61% in comparison to the Trio OptiTrack (CV = 4.04%) in a study that explored the reliability and concurrent validity of the Speed4Lift and 6 other commercially available velocity-measuring devices (28). Four total sets from both experimental conditions were analyzed; in the DS Condition, the warm-up set of 60% of the working-set load (DWU60) and the down set of the same load (DS60) were used. In the NDS Condition, both warm-up sets with 60% of the working-set load (WU60 and 2WU60) were analyzed. To determine mean concentric velocities (MCVs), the MCV of all 5 repetitions from a set was first calculated from the left and right LPT data sets. Then, the left and right LPT MCVs for these sets were averaged together for the statistical analysis. For the working sets, the MCV of each working set was determined, and then the 3 MCVs were averaged into one MCV representing all working sets. The CV of velocity measurements between the right and left LPTs was 3.19%.

Statistical Analyses

All data were collected and stored in the Speed4Lift iOS application software and then exported as a CSV file. Data were analyzed using the statistical software JASP (JASP Version 0.11.0.0) and expressed as mean and SDs. A Shapiro-Wilk test did not show a significant departure from normality ($p = 0.198$). A paired samples *t*-test was used to compare working-set MCVs of both conditions. A repeated measures ANOVA was used to assess differences in MCV between DWU60, DS60, WU60, and 2WU60. Mauchly's test demonstrated that the assumption of sphericity was violated ($p = 0.022$), and therefore, a Greenhouse-Geisser adjustment was used.

Cohen's d effect sizes and 95% confidence intervals of mean differences were reported for all comparisons; effect sizes were classified as trivial (<0.20), small (0.20–0.59), moderate (0.60–1.19), large (1.20–1.99), and very large (≥2.0) (23). The critical alpha was set at $p \leq 0.05$.

Results

There was no statistical difference ($t(11) = 0.852$, $p = 0.412$, Cohen's $d = 0.246$) for working-set MCVs between the DS condition (0.621 ± 0.116 m·s^{-1}) and the NDS condition (0.636 ± 0.129 m·s^{-1}). In addition, there was no significant difference for MCVs between DWU60, DS60, 1WU60, and 2WU60 ($F(1.681, 18.492) = 1.391$; $p = 0.270$). Effect sizes for comparisons between DWU60, DS60, 1WU60, and 2WU60 are displayed in Table 4. Tables 5 and 6 display MVCs for DWU60, DS60, 1WU60, 2WU60, and all working sets from the DS condition and NDS condition, respectively. The individual MCVs for DWU60, DS60, WU60, 2WU60, and the averages of all working sets for each subject are found in Table 7 and 8.

Discussion

This is the first study to the authors' knowledge that has specifically investigated whether down sets can be performed with greater movement velocities because of PAP from preceding heavier working sets. It has been suggested by Stone et al. (36) and Bompa and Haff (5) that the down sets are potentiated by target working sets and thus can be moved with greater concentric velocities. Stone et al. (36) observed this potentiation effect by manipulating the load sequencing in the midthigh pull. As such, training interventions aimed at improving maximal strength and power have often included down sets in strength-oriented exercises, such as back squats, barbell press variations, and weightlifting derivatives (25,26,34,35,37). Considering these exercises vary in their kinetic and kinematic profiles, this study was conducted to determine if successive heavy sets of back squats could augment concentric velocity during a lighter down set in strength-trained men.

The results of this study support our hypothesis that successive heavy sets of back squats would not acutely increase concentric velocity during a down set; in fact, concentric velocities in the down set were similar. In addition, there was no significant difference in velocities between the DS condition and the NDS condition when the down set was performed as an additional warm-up set.

The fitness-fatigue paradigm has been established as a theoretical foundation for PAP. In any protocol intended to use PAP, the conditioning activity conceptually increases an athlete's level of "fitness" through the stimulation of specific underlying neuromuscular mechanisms (36). Once the conditioning activity has been performed, fitness and fatigue are simultaneously increased; the rate at which fatigue decays is a critical component determining whether potentiation manifests or not. This difference between fitness and fatigue is known as "preparedness" and is theoretically elevated in a potentiated state (39). The current results suggest the set-repetition scheme used for the back squat did not allow sufficient rest for fatigue to dissipate, resulting in a muted potentiation effect. Although this scheme has been previously used in training programs and studies, other repetition schemes using fewer sets and repetitions per set along with higher intensities (3×3, 4×2, 3×2, etc.) have been coupled with down sets and may be

Table 3
No down set condition loading scheme.*

Set	Load
Warm-up set 1	Ten repetitions with 20 kg barbell
Warm-up set 2	Five repetitions at 40% of target for a working set
Warm-up set 3	Five repetitions at 60% of target for a working set
Warm-up set 4†	Five repetitions at 60% of target for a working set
Working-set 1	Five repetitions at 85% of 5RM
Working-set 2	Five repetitions at 85% of 5RM
Working-set 3	Five repetitions at 85% of 5RM

*5RM = 5 repetition maximum.
†Signifies different set placement compared with the no down set condition.

Table 4

Effect sizes and confidence intervals for comparisons between means for DWU60, DS60, 1WU60, and 2WU60 MCVs.

		95% of mean difference		
Comparison (mean ± *SD*)	Mean difference	Lower	Upper	Cohen's *d*
DWU60 (0.942 ± 0.175)				
DS60 (0.942 ± 0.175)	−1.667 × 10-4	−0.062	0.062	0.002
1WU60 (0.976 ± 0.167)	−0.034	−0.096	0.028	0.444
2WU60 (0.971 ± 0.151)	−0.029	−0.092	0.033	0.383
DS60 (0.942 ± 0.175)				
1WU60 (0.976 ± 0.167)	−0.034	−0.097	0.028	0.447
2WU60 (0.971 ± 0.151)	−0.030	−0.092	0.033	0.386
1WU60 (0.976 ± 0.167)				
2WU60 (0.971 ± 0.151)	0.005	−0.0058	0.067	0.062

better suited for potentiation purposes as the volume of conditioning activity is lower and the loads used are higher (32,34,37). The inherently greater range-of-motion along with eccentric and concentric portions in the back squat may have contributed to the accumulation of peripheral fatigue over the course of 3 sets of 5 repetitions. By contrast, the improvement in dynamic midthigh pull down set peak concentric velocity observed by Stone et al. (36) may have been due to less fatigue accumulation from the shorter range-of-motion and primarily concentric task. Because only back squats were assessed in this study, it is possible potentiation effects may be observed during down sets after exercises that are similar to midthigh pulls.

The back squat is often programmed for lower-body strength development because it is a free-weight, closed-kinetic chain exercise that recruits a large amount of muscle fibers, can be trained through a large range-of-motion, has a high degree of sport specificity, and can be overloaded with heavy loads; it is often used as a conditioning activity for these reasons (1,32,38,42,44). Dynamic strength-oriented exercises performed with an eccentric and concentric component may induce greater peripheral fatigue acutely, which may not be optimal for potentiation purposes (39). In addition, the velocity at which the eccentric phase is executed has been shown to affect the concentric velocity in the squat and bench press (9), which may be an important factor in modulating the expression of PAP (18). Finally, set-repetition schemes typically used with down sets involve performing more repetitions across sets (15,25,26,34,37) compared with the protocol used by Stone et al. (36), which would also contribute to undesirable levels of acute fatigue for PAP.

However, although other set-repetition configurations have been paired with down sets, the unpublished data from the dissertation of Carter et al. (8) indicate that it is unlikely PAP manifests during interset conditions in the dead-stop back squat (3 × 1 with 85% 1RM). The volume and intensity in this

Table 5

Down set condition MCVs.*

Set number	Load (% of working set)	Repetitions	MCV ± *SD*
1	20 kg bar	10	Not measured
2	40%	5	Not measured
3	60% (DWU60)	5	0.944 ± 0.175
4	100%	5	0.63 ± 0.119
5	100%	5	0.612 ± 0.121
6	100%	5	0.647 ± 0.14
7	60% (DS60)	5	0.942 ± 0.175

*5RM = 5 repetition maximum; MCV = mean concentric velocities.

Table 6

No down set condition MCVs.*

Set number	Load (% of working set)	Repetitions	MCV ± *SD*
1	20 kg bar	10	Not measured
2	40%	5	Not measured
3	60% (WU60)	5	0.976 ± 0.167
4	60% (2WU60)	5	0.971 ± 0.151
5	100%	5	0.64 ± 0.129
6	100%	5	0.621 ± 0.143
7	100%	5	0.622 ± 0.104

*MCV = mean concentric velocities.

protocol is in line with the protocols found to induce potentiation by Seitz and Haff (32) and likely did not induce significant fatigue considering single repetitions were performed and the subjects' average back squat 1RM to body mass ratio was 1.91 ± 0.36. Future investigations should determine whether other conditioning activities, set-repetition configurations, relative intensities, or rest intervals may be more effective to potentiate performance in the down set.

One study limitation was that the subjects were permitted to continue their routine training in addition to the testing procedures. Although the procedures were clearly outlined and all subjects were instructed to temporarily cease training 1–2 days before, their training was not monitored beyond specific questions asked about their recent training. However, some subjects had many years of experience training for weightlifting or strength development and had a general understanding of resistance training principles. When asked about their training before each session, all subjects adhered to performing no resistance training for the lower body and the weightlifters who trained upper body in between sessions kept training to a minimum so the effect of training-induced fatigue on the testing outcomes was minimized.

In addition, subjects were not provided a standardized training program before participation, which may have resulted in varying fitness levels at the study onset. As reported by their coach, several of the weightlifters who participated had recently completed a strength-endurance program and were in the initial phases of a maximal strength program. Suarez et al. (37) found slight depressions in the rate of force development measured from isometric midthigh pulls after a similar high-volume, strength-endurance program. The rate of force development increased

Table 7

Individual MCVs for DWU60 and DS60.*

Subject	DWU60	Working-set mean	DS60
1†	0.946	0.643	0.964
2†	1.166	0.862	1.227
3†	0.642	0.428	0.697
4†	0.768	0.62	0.862
5†	0.887	0.583	0.906
6	0.921	0.517	0.87
7	1.126	0.672	1.119
8	1.033	0.691	0.98
9	0.953	0.624	0.913
10	0.738	0.485	0.681
11	1.222	0.738	1.214
12	0.899	0.582	0.866

*MCV = mean concentric velocities.
†MCV of DS60 was higher than DWU60 (which may be a sign that post-activation potentiation occurred).

Table 8
Individual MCVs for 1WU and 2WU.

Subject	1WU	2WU	Working-set mean
1	1.034	0.9925	0.693
2	0.875	0.837	0.511
3	1.043	1.028	0.642
4	1.196	1.218	0.829
5	0.927	0.95	0.621
6	1.22	1.15	0.854
7	0.939	0.947	0.644
8	0.962	0.94	0.637
9	0.783	0.764	0.412
10	0.68	0.79	0.517
11	0.87	0.85275	0.549
12	1.182	1.185	0.717

above previous values as the training emphasis shifted from maximal strength to strength-power over several weeks (37). Other subjects were in the midst of general strength training programs to increase back squat, bench press, and deadlift strength. Thus, it is unknown whether subject's training volume before study participation affected potentiation outcomes during the down set, as previous training was not controlled. Future studies investigating the kinematic and kinetic characteristics of programming strategies could implement a standardized period (e.g., 4 weeks) of general strength training before initiating experimental conditions to obviate this limitation.

Subject's strength levels and the rest intervals used before the down sets may explain the lack of significant potentiation observed. A 1RM instead of a 5RM assessment would have provided a better indication of subjects' strength levels and thus potentiation capabilities, as the average back squat to body mass ratio (1.61 ± 0.25) of the subjects was calculated using an estimated 1RM (6). Seitz et al. (33) found that stronger rugby elite athletes (back squat 1RM ≥ 2.0 body mass) expressed a postactivation potentiation effect as early as 3 minutes postconditioning activity during a squat jump test, where the weaker individuals (back squat 1RM ≤ 2.0 body mass) displayed a significant postactivation potentiation effect 6 minutes postconditioning activity. In addition, a meta-analysis by Seitz and Haff (32) showed the stronger individuals (squat 1RM/body mass ≥ 2.0) were able to express greater potentiation effects (ES = 0.41) compared with weaker individuals (squat 1RM/body mass ≤ 2.0) (ES = 0.32) because of greater levels of fatigue resistance. Given the working-set MCVs in both conditions did not differ greatly, it is possible the current subjects were not strong enough to exhibit a PAP response during the down sets or a longer rest interval was needed after the working sets to dissipate fatigue before performing the down set. The results of Chaouachi et al. (10) suggest that exhibiting a PAP response during the down set may be possible with longer rest intervals; although they did not find significant potentiation when examining different time points postconditioning activity, they noticed that almost all individuals did potentiate but at different times. Nonetheless, the 3-minute rest interval was chosen to replicate the training scenarios that down sets are used in (15,26,34,35,37).

Finally, because of the onset of the COVID-19 pandemic, only 12 subjects were able to complete the study, limiting the statistical power of the results.

Practical Applications

The volume and intensity of back squats used in this study may not be appropriate to positively influence the velocity of a subsequent down set. Sequencing lighter loads after heavier loads within a training session may still be efficacious for developing power across a broad spectrum of loads, but the results of this study suggest those loads will not be moved with greater velocities. In fact, it may be preferable to use the warm-up period to perform the lighter loads, as MCVs were slightly, although not significantly, higher for the loads at 60% of the working set. Performing the loads in this sequence did not seem to negatively affect performance of the working sets. Follow-up studies are needed to verify these results. Down sets performed with basic strength training exercises such as back squats and deadlifts may be inherently limited as a power-training stimulus because of the deceleration of the barbell during a substantial portion of the concentric phase (14,17,43). By contrast, complete acceleration is produced through a full range-of-motion in ballistic exercises and weightlifting derivatives, resulting in significantly higher average velocity, peak velocity, average force, average power, and peak power compared with strength-oriented exercises (7,21,24,41). Incorporating these exercises in a strength and conditioning program as a power-development stimulus in lieu of lighter loads of strength exercises may produce superior adaptations long term. Future investigations should examine long-term changes in power development with athletes training using down sets.

Acknowledgments

The authors would like to acknowledge and thank all the volunteers who took the time out of their busy schedules to participate in this study.

References

1. Aagaard P, Simonsen EB, Andersen JL, Magnusson P, Dyhre-Poulsen P. Increased rate of force development and neural drive of human skeletal muscle following resistance training. *J Appl Physiol* 93: 1318–1326, 2002.
2. Baker D. Comparison of upper-body strength and power between professional and college-aged rugby league players. *J Strength Cond Res* 15: 30–35, 2001.
3. Baker D. A series of studies on the training of high-intensity muscle power in rugby league football players. *J Strength Cond Res* 15: 198–209, 2001.
4. Baker D, Nance S. The relation between running speed and measures of strength and power in professional rugby league players. *J Strength Cond Res* 13: 230–235, 1999.
5. Bompa, T, Haff, G. Chapter 10: strength and power development. In: *Periodization: Theory and Methodology of Training*. Champaign, IL: Human Kinetics. pp. 279.
6. Brzycki, M. Strength testing: Prediction of one-rep max from repetitions to-fatigue. *J Health Phys Educ Rec Dance* 64: 88–90, 1993.
7. Canavan PK, Garrett GE, Armstrong LE. Kinematic and kinetic relationships between an olympic-style lift and the vertical jump. *J Strength Cond Res* 10: 127–130, 1996.
8. Carter C. *Kinetic, Kinematic, and Metabolic Response of Low Volume Accentuated Eccentric Loading in Collegiate Weightlifters. Electron Theses Diss*, 2013. Available at: https://dc.etsu.edu/etd/1193. Accessed: March 10, 2019.
9. Carzoli JP, Sousa CA, Belcher DJ, et al. The effects of eccentric phase duration on concentric outcomes in the back squat and bench press in well-trained males. *J Sports Sci* 37: 2676–2684, 2019.
10. Chaouachi A, Poulos N, Abed F, et al. Volume, intensity, and timing of muscle power potentiation are variable. *Appl Physiol Nutr Metab* 36: 736–747, 2011.

11. Comfort P, Jones PA, McMahon JJ. Chapter 10—Isometric and dynamic testing. In: *Performance Assessment in Strength and Conditioning*. Oxon: Routledge. pp. 185.
12. Cormie P, McCaulley GO, Triplett NT, McBride JM. Optimal loading for maximal power output during lower-body resistance exercises. *Med Sci Sports Exerc* 39: 340–349, 2007.
13. Cormie P, McGuigan MR, Newton RU. Developing maximal neuromuscular power. *Sports Med* 41: 125–146, 2011.
14. Cronin JB, McNair PJ, Marshall RN. Is velocity-specific strength training important in improving functional performance?. *J Sports Med Phys Fitness* 42: 267–273, 2002.
15. DeWeese BH, Hornsby G, Stone M, 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.
16. DeWeese BH, Serrano AJ, Scruggs SK, Burton JD. The midthigh pull: Proper application and progressions of a weightlifting movement derivative. *Strength Cond J* 35: 54–58, 2013.
17. Elliott B, Wilson G, Kerr G. A biomechanical analysis of the sticking region in the bench press. *Med Sci Sports Exerc* 21: 450–462, 1989.
18. Esformes JI, Keenan M, Moody J, Bampouras TM. Effect of different types of conditioning contraction on upper body postactivation potentiation. *J Strength Cond Res* 25: 143–148, 2011.
19. Gepfert M, Golas A, Zajac T, Krzysztofik M. The use of different modes of post-activation potentiation (PAP) for enhancing speed of the slide-step in basketball players. *Int J Environ Res Public Health* 17: 5057, 2020.
20. Gołaś A, Maszczyk A, Zajac A, Mikołajec K, Stastny P. Optimizing post activation potentiation for explosive activities in competitive sports. *J Hum Kinet* 52: 95–106, 2016.
21. Haff GG, Nimphius S. Training principles for power. *Strength Cond J* 34: 2–12, 2012.
22. Häkkinen K, Pakarinen A, Alen M, Kauhanen H, Komi PV. Neuromuscular and hormonal adaptations in athletes to strength training in two years. *J Appl Physiol* 65: 2406–2412, 1988.
23. Hopkins WG. *A New View of Statistics: A Scale of Magnitude for Effect Statistics*, 2002.
24. Hori N, Newton RU, Nosaka K, Stone MH. Weightlifting exercises enhance athletic performance that requires high-load speed strength. *Strength Cond J* 27: 50–55, 2005.
25. Hornsby WG, Gentles JA, MacDonald CJ, Mizuguchi S, Ramsey MW, Stone MH. Maximum strength, rate of force development, jump height, and peak power alterations in weightlifters across five months of training. *Sports* 5: 78, 2017.
26. Painter KB, Haff GG, Ramsey MW, et al. Strength gains: Block versus daily undulating periodization weight training among track and field athletes. *Int J Sports Physiol Perform* 7: 161–169, 2012.
27. Pajerska K, Zajac T, Mostowik A, Mrzyglod S, Golas A. Post activation potentiation (PAP) and its application in the development of speed and explosive strength in female soccer players: A review. *J Hum Sport Exerc*: in press, 2020.
28. Pérez-Castilla A, Piepoli A, Garrido-Blanca G, Delgado-García G, Balsalobre-Fernández C, García-Ramos A. Precision of 7 commercially available devices for predicting bench-press 1-repetition maximum from the individual load–velocity relationship. *Int J Sports Physiol Perform* 14: 1442–1446, 2019.
29. *Periodization: Theory and Methodology of Training*. Champaign, IL: Human Kinetics. pp. 279.
30. Sale DG. Postactivation potentiation: Role in human performance. *Exerc Sport Sci Rev* 30: 138–143, 2002.
31. Sale DG. Neural adaptation to strength training. In: *Strength and Power in Sport*. Hoboken, NJ: John Wiley & Sons, Ltd, 2008. pp. 281–314.
32. Seitz LB, Haff GG. Factors modulating post-activation potentiation of jump, sprint, throw, and upper-body ballistic performances: A systematic review with meta-analysis. *Sports Med Auckl NZ* 46: 231–240, 2016.
33. Seitz LB, de Villarreal ES, Haff GG. The temporal profile of postactivation potentiation is related to strength level. *J Strength Cond Res* 28: 706–715, 2014.
34. Stone MH, Pierce KC, Sands WA, Stone ME. Weightlifting: Program design. *Strength Cond J* 28: 10–17, 2006.
35. Stone MH, Sanborn K, O'bryant HS, et al. Maximum strength-power-performance relationships in collegiate throwers. *J Strength Cond Res* 17: 739–745, 2003.
36. Stone MH, Sands WA, Pierce KC, Ramsey MW, Haff GG. Power and power potentiation among strength–power athletes: Preliminary study. *Int J Sports Physiol Perform* 3: 55–67, 2008.
37. Suarez DG, Mizuguchi S, Hornsby WG, Cunanan AJ, Marsh DJ, Stone MH. Phase-specific changes in rate of force development and muscle morphology throughout a block periodized training cycle in weightlifters. *Sports Basel Switz* 7: 129, 2019.
38. Suchomel TJ, Nimphius S, Bellon CR, Stone MH. The importance of muscular strength: Training considerations. *Sports Med Auckl NZ* 48: 765–785, 2018.
39. Tillin NA, Bishop D. Factors modulating post-activation potentiation and its effect on performance of subsequent explosive activities. *Sports Med Auckl NZ* 39: 147–166, 2009.
40. Turner AN, Comfort P, McMahon J, et al. Developing powerful athletes, Part 1: Mechanical underpinnings. *Strength Cond J* 42: 30–39, 2020.
41. Turner AN, Comfort P, McMahon J, et al. Developing powerful athletes Part 2: Practical applications. *Strength Cond J*, 2020.
42. Weber KR, Brown LE, Coburn JW, Zinder SM. Acute effects of heavy-load squats on consecutive squat jump performance. *J Strength Cond Res* 22: 726–730, 2008.
43. Wilson GJ, Elliott BC, Kerr GK. Bar path and force profile characteristics for maximal and submaximal loads in the bench press. *J Appl Biomech* 5: 390–402, 1989.
44. Wisloff U, Castagna C, Helgerud J, Jones R, Hoff J. Strong correlation of maximal squat strength with sprint performance and vertical jump height in elite soccer players. *Br J Sports Med* 38: 285–288, 2004.
45. Zamparo P, Minetti AE, di Prampero PE. Interplay among the changes of muscle strength, cross-sectional area and maximal explosive power: Theory and facts. *Eur J Appl Physiol* 88: 193–202, 2002.