THE ACUTE EFFECT OF DIFFERENT HALF SQUAT SET CONFIGURATIONS ON JUMP POTENTIATION

DANIEL A. BOULLOSA,[1] LAURINDA ABREU,[2] LUIS G.N. BELTRAME,[1] AND DAVID G. BEHM[3]

[1]Post-Graduate Program in Physical Education, Catholic University of Brasilia, Brasilia, Brazil; [2]Lavadores, Vigo, Spain; and [3]School of Human Kinetics and Recreation, Memorial University of Newfoundland, St. John's Newfoundland, Canada

ABSTRACT

Boullosa, DA, Abreu, L, Beltrame, LGN, and Behm, DG. The acute effect of different half squat set configurations on jump potentiation. *J Strength Cond Res* 27(8): 2059–2066, 2013—The aim of this study was to evaluate the acute effect of a half squat exercise performed with different set configurations on jump potentiation. Twelve resistance-trained men were evaluated on 3 occasions separated by 48–96 hours. First, they performed a 5 repetitions maximum (5RM) test. Subsequently, they performed in a randomized order 2 sessions: one session with 5RM until failure and the other with the same workload but with 30-second rest intervals between repetitions (i.e., cluster set [CS]). Countermovement jump performance was examined during the second and third sessions for jump height and force-time parameters using a force platform at the following time intervals: before and at 1, 3, 6, 9, and 12 minutes. Separate comparisons for each variable at the different time intervals were analyzed using analysis of variance, effect size, and qualitative inferences. The majority of the parameters improved independently of the time they occurred, except for peak force and vertical stiffness after a set until failure. For peak power, it appears that the cluster treatment resulted in superior potentiation at 1 minute, whereas the 5RM treatment resulted in greater potentiation at 9 minutes. Effect size analysis and qualitative outcomes revealed an improvement in vertical stiffness and a lowering in the depth of the countermovement in CS. There were significant correlations between participants' 5RM relative performance and various force-time parameters only in CS. It appears that a CS induces greater peak power than a 5RM set at 1 minute, although the reverse occurs at 9 minutes. Delayed potentiation associated with the 5RM may be attributed to greater fatigue versus the CS approach. Therefore, it follows that the optimal method for inducing peak power potentiation is dependent on the available time between heavy half squat exercise and the subsequent jump performance.

KEY WORDS postactivation potentiation, fatigue, complex training, warm-up, resistance training

INTRODUCTION

Postactivation potentiation (PAP) refers to the phenomena by which muscular performance characteristics are acutely enhanced as a result of their contractile history (25). Although PAP can provide physiological enhancement, it is not always related to functional performance improvements (13). For instance, increases in peak power (physiological parameter) during the push-off of a jump-after-squat exercises have been previously observed without any increment in jump height (functional performance) (4,16,22). These and other previous reports suggest that potentiation could be evident depending on the method of evaluation and the parameters selected for analysis, with the fatigue-potentiation relationship modulating the acute effect of the conditioning exercise during recovery (1,3,24). Interestingly, in the recent article of Chaouachi et al. (4), the potentiation of selected parameters during jumping after various workloads of half squat exercises was quite variable between individuals, with a significant deterioration of the jump capacity observed (4). This fact could explain the conflicting results in previous literature (25). Therefore, because the individual response to conditioning stimuli is important for the fatigue-potentiation interaction and its influence on subsequent performance, it is necessary to explore new strategies for designing conditioning protocols that concurrently enhance potentiation and limit the fatiguing response for optimal performance. This could help also for clarifying the inconsistency in PAP responses previously reported that could be related to the masking effect of fatigue on potentiation (1).

Set configuration is one of the variables that could be modified when designing resistance and jump exercises (9,10). Recently, various studies have suggested that introducing rest intervals between exercise repetitions instead of between sets (i.e., cluster training) could be an effective method for improving mechanical performance (7) with a lower loss of velocity and power over the whole training session (12,17), allowing also a greater training volume (7,15). Regarding resistance, this better performance could be

---

Address correspondence to Dr. Daniel A. Boullosa, d_boullosa@yahoo.es.

27(8)/2059–2066

Journal of Strength and Conditioning Research

explained by the fact that with cluster training, it is the reduced time under tension that has been suggested to be a key factor for muscular fatigue development in resistance (26). Moreover, Hardee et al. (11) have recently reported a lower rating of perceived exertion with the introduction of rest intervals between repetitions during clean pulls when compared with the same load with traditional set configuration. Thus, it may be suggested that cluster training is an effective strategy for improving mechanical performance with a lower development of fatigue in resistance. This could be an interesting approach for conditioning stimuli when looking for potentiation responses during complex training sessions or during competitions. However, to the best of our knowledge, there are no studies comparing the acute responses of cluster training with traditional set configuration. This information would be valuable for designing more effective and efficient conditioning activities in those sports requiring power performances such as jumping, sprinting, or even team sports.

Therefore, the aim of this study was to compare the acute effect on jump capacity of different set configuration with the same workload (i.e., cluster set [CS] vs. set until failure) of half squats. These exercises were selected because most PAP studies have used them and they are closed kinetic chain activities (greater sport specificity). It was hypothesized that a CS could favor a greater magnitude and a more rapid potentiation response while jumping because of the lower fatigue development when compared with a set until failure.

METHODS

Experimental Approach to the Problem

After determination of the load corresponding to 5 repetition maximum (5RM) in half squat, participants were assessed in a random order on 2 separate occasions for comparing the acute effect (i.e., at 1, 3, 6, 9, and 12 minutes of recovery) of this workload with different set configurations (i.e., set until failure vs. CS) on jump performance and the associated force-time parameters. The independent variable was set configuration, whereas jump height and kinetic parameters over the whole recovery were the dependent variables.

Subjects

Twelve aspiring firefighters volunteered for participation in this study. Their characteristics are presented in Table 1. All of them had a minimum of 6 months of experience in resistance training and countermovement jump (CMJ) evaluations. Their training routines included resistance training, power exercises, sprinting, aerobic running, swimming, and agility as other specific firefighting skills. Their performance level was very heterogeneous, with mean best performances of ~100 kg in bench press RM, ~20 pull-ups, ~12 seconds in 100 m, ~3 minutes in 1,000 m, and ~1 minute 20 seconds in 100-m freestyle. After receiving a detailed explanation of the procedures of the study, participants provided informed written consent. The study received the approval of the local ethics committee for experimentation with human subjects.

TABLE 1. Participants' characteristics.*

Characteristics	Mean ± *SD*
Age (y)	25.5 ± 4.9
Height (cm)	178.2 ± 8.3
Body mass (kg)	77.7 ± 7.8
Body fat (%)	9.6 ± 2.2
5RM half squat (kg)	181.4 ± 24.1
5RM half squat/body mass	2.4 ± 0.3

*5RM = 5 repetitions maximum.

Experimental Design and Procedures

This experiment was performed in February in Spain. During these days, participants executed low- to medium-intense activities for fitness maintenance. Half squat was selected because it is the exercise most used with leg power conditioning and for obtaining potentiation responses (18). The load of 5RM was also selected because it usually represents >80% RM, which may be a sufficient intensity for inducing potentiation while jumping (25). Participants were fully familiarized with the procedures.

After a brief warm-up of 10 minutes of easy running on a treadmill, 5 minutes of calisthenics, and 20 repetitions of abdominal crunches, participants were instructed to perform a half squat 5RM test. All the procedures were supervised by the primary investigator who was also the physical coach for the participants at that time. The half squat was performed with free weights until 90° of knee flexion was achieved. The progression of the test was as follows, with 3–5 minutes of rest between sets: 10 repetitions of an estimated 50% RM, 5 repetitions of an estimated 70% RM, and subsequent attempts of 3 repetitions of estimated 5RM until the maximum load was determined and fully executed without technical difficulties. All participants achieved their 5RM with no more than 6 sets over the whole test. We decided not to include additional evaluations for determining testing reproducibility because they were habitually training with this exercise load. Therefore, a high reproducibility and reliability could be expected. Additionally, more testing sessions could have an influence on performance changes, thus biasing results. The highest load was selected for the next 2 experimental sessions.

After determination of the best 5RM, participants performed the experimental protocols in a randomized order, with a minimum of 48 hours and a maximum of 96 hours between sessions. All the sessions were performed during the morning at the same time of the day for each participant. They were asked not to drink caffeine beverages 1 hour before evaluations. They were allowed to drink water "ad libitum" during the whole experiment. Both experimental sessions included the previously described warm-up plus a set of 5 repetitions at 50% of 5RM and 2 maximal CMJs separated by 15 seconds. The best CMJ was selected for further analysis. After 3 minutes of rest, they performed a set of 5RM (i.e., traditional set configuration) or the same load but with 30-second recovery intervals (15) between half squat repetitions (i.e., CS).

After the end of the half squat exercise, participants performed 2 CMJs separated by ~15 seconds, at 1, 3, 6, 9, and 12 minutes of recovery. They were instructed to jump as high as possible. The CMJs were performed on a force plate (Quattro Jump; Kistler, Winterthur, Switzerland) where vertical forces were recorded with a sampling rate of 500 Hz. Participants freely chose the depth of the countermovement. Based on a previous study (3), the kinetic parameters selected for analysis were as follows: peak power ($\mathrm{W \cdot kg^{-1}}$), maximum force relative to body weight, normalized stiffness ($\mathrm{N \cdot m^{-1} \cdot kg^{-1}}$), and vertical displacement of center of mass during countermovement (cm). Peak power and stiffness were normalized to provide a better comparison between participants of differing body mass (Table 1).

Statistical Analyses

Descriptive data are presented as mean ± *SD*. The normality distribution of variables was examined with the Kolmogorov-Smirnov test. Effects of each conditioning protocol on jump-related parameters at different times were assessed using analysis of variance (ANOVA) for repeated measurements (2 conditioning protocols × 6 time points) with pairwise Bonferroni correction. Baseline values were further compared with the peak of each dependent variable, regardless at which time the peak occurred (4), by means of paired Student's *t*-test. Comparisons between measurements at peak height time and baseline were also performed. The

Table 2. Force-time parameters of the CMJ after isolating the peak of each dependent variable and comparing it with the baseline, regardless of at which time point the peak occurred (A) and force-time parameters associated with the best jump height (B).*†

A) Condition	Baseline	Peak	*p*	%Δ; ±90% CL	ES	Qualitative inference
CMJ (cm)						
Traditional	44.68 ± 4.47	45.85 ± 4.44	0.030	2.70; ±1.9	0.26	Possibly
Cluster	45.12 ± 4.60	46.29 ± 5.02	0.019	2.57; ±1.7	0.24	Possibly
Peak power ($\mathrm{W \cdot kg^{-1}}$)						
Traditional	52.12 ± 5.02	53.39 ± 5.83	0.031	2.36; ±1.7	0.23	Possibly
Cluster	51.27 ± 5.87	52.45 ± 5.58	0.025	2.41; ±1.8	0.20	Possibly
Peak force (BW)						
Traditional	2.37 ± 0.21	2.46 ± 0.25	0.121	3.99; ±4.3	0.39	Possibly
Cluster	2.31 ± 0.28	2.48 ± 0.26	0.004	7.48; ±3.6	0.61	Very likely
Vertical displacement of center of mass (cm)						
Traditional	29.91 ± 4.11	33.27 ± 4.71	0.003	11.67; ±5.5	0.76	Very likely
Cluster	31.64 ± 4.74	34.18 ± 4.26	0.003	8.69; ±4.1	0.56	Very likely
Vertical stiffness ($\mathrm{N \cdot m^{-1} \cdot kg^{-1}}$)						
Traditional	81.99 ± 10.93	88.36 ± 17.61	0.133	7.70; ±8.5	0.43	Likely positive
Cluster	76.07 ± 14.35	88.39 ± 19.69	0.002	16.02; ±7.1	0.72	Very likely

B) Condition	Baseline	Values at peak height	*p*	%Δ; ±90% CL	ES	Qualitative inference
Peak power ($\mathrm{W \cdot kg^{-1}}$)						
Traditional	52.12 ± 5.02	52.53 ± 6.08	0.544	0.69; ±2.0	0.07	Likely trivial
Cluster	51.27 ± 5.87	51.38 ± 5.71	0.752	0.27; ±1.5	0.02	Very likely trivial
Peak force (BW)						
Traditional	2.37 ± 0.21	2.37 ± 0.23	0.937	−0.014; ±0.32	0.02	Most likely trivial
Cluster	2.31 ± 0.28	2.35 ± 0.27	0.534	2.02; ±5.7	0.14	Unclear
Vertical displacement of center of mass (cm)						
Traditional	29.91 ± 4.11	31.32 ± 5.26	0.226	4.99; ±7.0	0.30	Possibly
Cluster	31.64 ± 4.74	30.64 ± 4.50	0.184	−2.87; ±3.6	0.22	Possibly trivial
Vertical stiffness ($\mathrm{N \cdot m^{-1} \cdot kg^{-1}}$)						
Traditional	81.99 ± 10.93	79.07 ± 14.40	0.430	−3.33; ±7.3	0.23	Unclear
Cluster	76.07 ± 14.35	79.72 ± 14.75	0.220	5.58; ±7.7	0.25	Possibly

*CMJ = countermovement jump; ES = effect size; BW = body weight.

†Values are mean ± *SD*. Magnitudes of differences are expressed as mean percentage change (%Δ) and 90% confidence limits (±90% CL).

TABLE 3. Correlations among parameters at jump peak height. Pearson's *r* (with 90% confidence intervals), *p* values, and qualitative inferences are shown.*

	ΔPeak power	ΔPeak force	ΔVertical stiffness	ΔVertical displacement of center of mass
Cluster condition				
ΔCMJ	$r = 0.21$ (–0.32 to 0.64) $p = 0.530$ Unclear	0.45 (–0.06 to 0.78) 0.161 Likely	0.10 (–0.42 to 0.57) 0.771 Unclear	0.41 (–0.12 to 0.75) 0.215 Unclear
ΔPeak power		0.51 (0.02 to 0.81) 0.108 Likely	0.69 (0.29 to 0.88) 0.020 Very likely	–0.48 (–0.79 to 0.03) 0.135 Likely
ΔPeak force			0.79 (0.48 to 0.92) 0.004 Most likely	–0.03 (–0.52 to 0.48) 0.940 Unclear
ΔVertical stiffness				–0.63 (–0.86 to –0.19) 0.038 Very likely
Traditional condition				
ΔCMJ	$r = –0.09$ (–0.56 to 0.43) $p = 0.793$ Unclear	0.31 (–0.23 to 0.70) 0.360 Unclear	–0.26 (–0.67 to 0.27) 0.436 Unclear	0.43 (–0.10 to 0.78) 0.185 Unclear
ΔPeak power		0.51 (0.01 to 0.80) 0.112 Likely	0.94 (0.83 to 0.98) 0.000 Most likely	–0.82 (–0.94 to –0.55) 0.002 Most likely
ΔPeak force			0.51 (0.01 to 0.80) 0.112 Likely	–0.07 (–0.55 to 0.44) 0.826 Unclear
ΔVertical stiffness				–0.89 (–0.96 to –0.71) 0.000 Most likely

*Δ = change from baseline to the value associated with the best jump height; CMJ = countermovement jump.

magnitude of baseline-to-peak changes was assessed using effect size (ES) and percentage of change. Threshold values for ES were 0.2 (small), 0.6 (moderate), 1.2 (large), and 2.0 (very large) (14). Confidence intervals (90%) for the true mean change were also estimated. Magnitude-based inferences about the true change were made with reference to the smallest worthwhile change calculated as follows: 0.2 multiplied by the between-subject *SD* expressed as coefficient of variation (CV%). Quantitative chances of substantial positive, trivial, or negative changes were assessed qualitatively as follows: <0.5%, almost certainly not; 0.5–5%, very unlikely; 5–25%, unlikely; 25–75%, possibly; 75–95%, likely; 95–99.5%, very likely; and >99.5%, almost certainly. If the chance of having positive or negative changes were both >5%, the true difference was deemed unclear (14). Relationships between parameters were identified using Pearson product-moment correlation coefficient (r). Confidence intervals (90%) for coefficients of correlation were also estimated. The following criteria were adopted for interpreting the magnitude of correlations between parameters: <0.1, trivial; 0.1–0.3, small; 0.3–0.5, moderate; 0.5–0.7, large; 0.7–0.9, very large; and 0.9–1.0, almost perfect. If the 90% confidence intervals overlapped the thresholds for substantially positive or negative values, the magnitude was considered unclear. Inferences about correlations were made with respect to a smallest worthwhile correlation of 0.1. Differences in time to peak for each jump-related parameter were analyzed by paired Student's t-test with a complementary ES calculation. Statistically significant level was set at a p value of ≤ 0.05. Statistical analysis was conducted with the SPSS software (v17.0; SPSS, Inc., Chicago, IL, USA).

RESULTS

The ANOVA revealed no significant main effects for jump-related parameters. Peak power showed a tendency for the time factor ($p = 0.051$) and a significant interaction between the protocol and time factors ($p = 0.048$). Simple effect analyses revealed that peak power was higher at 1 minute after CS when compared with the traditional set configuration (51.8 ± 5.5 vs. 50.9 ± 4.6 $W \cdot kg^{-1}$, $p = 0.046$). Conversely, peak power was lower at 9 minutes after CS when compared with the traditional set configuration (50.5 ± 5.9 vs. 51.8 ± 5.5 $W \cdot kg^{-1}$, $p = 0.039$). No other significant interactions were observed.

Peak values of jump height and force-time parameters during CMJ, independently of the time at which they occurred, are presented in Table 2A. Interestingly, the majority of the parameters improved significantly, except for peak force and vertical stiffness after traditional set configuration.

Force-time parameters associated with the best jump height are presented in Table 2B. Despite any significant change detected, it is interesting to note an opposite trend in vertical stiffness and vertical displacement of the center of mass between conditions, as inferred from ES and qualitative outcomes. Thus, CS configuration demonstrated an improvement in vertical stiffness with a lowering in the depth of the countermovement, whereas traditional set configuration

TABLE 4. Time (minutes) to peak data of jump height and force-time parameters, and statistical differences (p values and effect size) among these parameters between conditions and during each condition.*

	Min of peak value (mean ± *SD*)			
	Traditional protocol	Cluster protocol	p	ES
CMJ height	6.1 ± 3.3	3.6 ± 2.9	0.042	0.84
Peak power	4.4 ± 2.5	4.4 ± 4.7	0.951	0.03
Peak force	4.9 ± 4.2	4.4 ± 4.0	0.537	0.20
Vertical stiffness	4.1 ± 3.5	5.7 ± 4.5	0.249	0.32
Vertical displacement of center of mass	8.7 ± 3.5	5.8 ± 2.4	0.052	0.83

	Peak power	Peak force	Vertical stiffness	Vertical displacement of center of mass
Traditional protocol, p (ES)				
CMJ height	0.054 (0.61)	0.279 (0.32)	0.205 (0.60)	0.049 (0.75)
Peak power		0.550 (0.16)	0.833 (0.09)	0.020 (1.44)
Peak force			0.547 (0.24)	0.060 (0.98)
Vertical stiffness				0.034 (1.31)
Cluster protocol, p (ES)				
CMJ height	0.701 (0.19)	0.683 (0.16)	0.077 (0.71)	0.154 (0.67)
Peak power		0.892 (0.04)	0.276 (0.44)	0.433 (0.31)
Peak force			0.065 (0.51)	0.368 (0.39)
Vertical stiffness				0.665 (0.23)

*ES = effect size; CMJ = countermovement jump.

showed an impairment in vertical stiffness with an increment in the depth of the countermovement.

Correlations among parameters at jump peak height are shown in Table 3. Surprisingly, Δpeak power was not correlated with Δjump height in any condition but exhibited a correlation with Δvertical stiffness in both conditions. Moreover, Δvertical stiffness was correlated with Δpeak force only in the cluster condition. Additionally, an inverse relationship between Δvertical stiffness and the Δvertical displacement of the center of mass in both conditions was observed.

Times to peak of all jump parameters are presented in Table 4. Interestingly, a more rapid increment in jump height was observed in the cluster condition when compared with the traditional set configuration ($p = 0.042$), with a tendency detected ($p = 0.052$) for the vertical displacement of the center of mass. Additionally, various correlations were detected among strength and peak force-time parameters but only in the cluster condition (5RM/body mass − Δvertical stiffness, $r = -0.839$, $p = 0.005$; 5RM/body mass − Δpeak force, $r = -0.645$, $p = 0.061$; 5RM − time to peak value of vertical displacement of center of mass, $r = -0.602$, $p = 0.039$).

DISCUSSION

The main finding of this study was that different set configurations have different acute effects on potentiation while jumping. Thus, introducing recovery intervals between half squat repetitions (i.e., cluster training) seems to allow a more rapid improvement of jump height and a greater potentiation of various force-time parameters when compared with a set until failure, probably as a consequence of the better fatigue-potentiation relationship in the cluster condition. These findings are of great interest for athletes and coaches who would like to optimize their training routines and their competitive warm-ups on an individual basis.

In line with the recent work of Chaouachi et al. (4), the potentiation of force-time parameters in the current study was also variable among individuals. In contrast, our protocols could induce significant improvements in peak jump height, whereas these authors (4) did not observe any significant change in peak jump height independently of the time considered. Moreover, although the ANOVA of this previous study (4) showed an impairment of jump capacity after all protocols, we did not find any significant change in jump height with the ANOVA. Previous studies have suggested that factors like training experience and exercise load could modulate the potentiation-fatigue interaction for subsequent performance (2,22). Thus, it is interesting to note that a similar load (i.e., 5RM ≈ 85%RM), as employed in the previous study (4) (i.e., 70–90% RM), elicited better performance in the current study. This intriguing result is in line with previous literature in which the potentiation response after similar protocols was not consistent, which could be related to participants' characteristics and training background (5,19,29). In this respect, our participants could not be considered elite-level athletes because they trained concurrently antagonistic physical capabilities such as endurance and explosiveness. Hence, a lower potentiation response could be expected in the current study (5,19). Although we do not know the exact reason for such a difference, it is tempting to speculate that our protocols may induce a better fatigue-potentiation relationship because the half squats were performed until 90° knee flexion, whereas the participants of the previous study performed parallel squats (4). This hypothesis could be supported by the previous report of Place et al. (20) that showed a greater post-twitch potentiation after fatiguing contractions at short quadriceps muscle lengths when compared with long muscle lengths but with a similar level of fatigue between conditions. Similarly, it may be suggested that participants of our study could experience a greater potentiation after squats because of the lower level of knee flexion. Therefore, further studies should elaborate on the potentiation-fatigue response to various exercises and workloads, and more specifically with regard to the level of knee flexion during squats.

Interestingly, the different levels of potentiation on force-time parameters after both protocols (failure vs. cluster) allowed a similar magnitude of peak height increments. However, the difference between conditions was evident on the significantly different time to peak height (3.6 ± 2.9 vs. 6.1 ± 3.3 minutes, for CS and failure set, respectively, $p = 0.042$). Furthermore, the timing of the appearance of peak values of selected parameters was protocol-dependent, with the traditional set configuration exhibiting a lower synchronization among parameters (Table 4). This could reflect different jump coordination between conditions (4,23). For instance, the peak values for the vertical displacement of the center of mass occurred at very different time periods (8.7 ± 3.5 vs. 5.8 ± 2.4 minutes, $p = 0.052$, for traditional set and CS configurations, respectively), with the direction on such changes being opposite. Moreover, the absence of correlations between Δpeak power and Δjump height is surprising and may indicate an altered motor control after both protocols because these parameters were highly correlated at baseline (i.e., 0.754 and 0.797, $p < 0.01$, for traditional set and CS configurations, respectively). In this regard, the differences revealed by ANOVA in peak power at 1 and 9 minutes of recovery between conditions reinforce this assumption. Because the intensity of both protocols could be of similar magnitude, the inclusion of rest intervals between repetitions in the cluster condition may be considered the major factor for such differences between protocols. Thus, the fatigue effects possibly caused by metabolic byproducts and greater neural fatigue may have delayed this potentiation response (1) after the traditional set configuration because similar volumes resulted in similar net potentiation of peak power in both conditions. Additionally, it should be noted that the completion time between the first and the last repetition in each condition was quite different (e.g., ~2 minutes 30 seconds vs. ~15 seconds). This consideration is important when performing multiple set sessions.

Further studies should elaborate on this observation of a delayed appearance of potentiation after traditional set configuration with different training volumes (e.g., number of sets), exercise intensities (e.g., 3RM), and other exercises (e.g., bench press).

These differences in correlations among parameters between conditions may be also influenced by the fact that force-time parameters like vertical stiffness and peak force are recorded at the end of the eccentric action, whereas peak power is recorded near the end of the take off (6), thus suggesting an elastic energy transfer (28) that could be also influenced by the potentiation-fatigue interaction (3). This consideration is important because the interaction of these phenomena could depend on the muscular regime and the muscle length (21). The existence of an elastic energy transfer could be supported by the high correlations observed (Table 3) between Δpeak power and Δvertical stiffness in both conditions. In this regard, Vuorimaa et al. (27) previously observed a lowering in electromyographic activity with a concurrent increment in mean power during half squat exercises, thus suggesting a possible increase in elastic energy transfer after various running-conditioning protocols. More recently, Moir et al. (18) reported a greater stiffness increment after high-intensity, when compared with high-volume, back squats but with no augmentation of the jump height. Therefore, further studies should be conducted for the assessment of electromyography concurrently with kinetic parameters for evaluating the influence of the fatigue-potentiation relationship on the elastic energy transfer and jump coordination after different conditioning protocols.

Of further interest are the correlations found among half squat performance and force-time parameters only after the cluster protocol. This is a novel finding with our results suggesting that the stronger the athlete, the lower and the more anticipated was the increase of force-time parameters over the eccentric movement of the push-off phase. Because these findings are related only to the cluster condition, it may be speculated that a different response could occur with different loads (e.g., heavier loads). Thus, it may be suggested that a heavier load could induce a greater response in the stronger athletes because the load of 5RM may not be the optimal stimulus for them with such a load. Conversely, the absence of correlations among these parameters after the traditional set configuration may suggest that the possible influence of strength level on such relationships could be masked by other factors such as fatigue resistance (4). In this respect, it should be considered that the training background of our participants do not favor maximum power performances but a greater endurance capacity. Therefore, it is possible that our specific participants (i.e., aspiring firefighters) may possess a greater recovery capacity when compared with other athletes with greater power but lower endurance capacity. Further studies could explore the influence of strength levels concurrently with fatigue resistance with respect to the load and set configuration of conditioning activities.

In summary, a set with the load equivalent to 5RM of half squats performed with interrepetition rest intervals of 30 seconds favors a more rapid appearance and a greater potentiation of various kinetic parameters during vertical jumping, when compared with a set of 5RM until failure (without rest intervals). Further studies are needed for testing the effectiveness of cluster training in other exercises, for competition, and the chronic effect of complex training performed with CS on performance (8). Furthermore, additional variations of CS (e.g., inclusion of dynamic stretching and altering pause duration) should be examined regarding their relative potentiation effects on subsequent exercises by individuals with designated training backgrounds. Additionally, more studies are needed with greater training volumes and with other intensities for determining the best dose-response model during conditioning activities.

PRACTICAL APPLICATIONS

The optimal method for inducing peak power potentiation is dependent on the available time between heavy half squat exercise and subsequent jump performance. It appears that CS may be a superior approach to a 5RM approach before jump performance if the time available is close to 1 minute, whereas the 5RM approach may be superior if close to 9 minutes is available for individuals trained in both power and endurance capacities who have been engaged in heavy resistance training for no less than the previous 6 months. Additionally, it may be suggested that the employment of force plates is recommended for a more precise evaluation of jump potentiation because the potentiation of various kinetics parameters at different times could be expected with no observable increment in jump height. This approach could be interesting for determining the appropriate workloads for warming up in different sports as for designing complex training sessions on an individual basis.

ACKNOWLEDGMENTS

We thank Dr. Miguel Fernández-del-Olmo for his support in data collection. We recognize the facilities provided by Atenas Gimnasio C.B. during the experiment. We also thank the athletes for their participation. The results of the present study do not constitute endorsement by the authors or the National Strength and Conditioning Association.

REFERENCES

1. Behm, DG, Button, DC, Barbour, G, Butt, JC, and Young, WB. Conflicting effects of fatigue and potentiation on voluntary force. *J Strength Cond Res* 18: 365–372, 2004.
2. Boullosa, DA and Tuimil, JL. Postactivation potentiation in distance runners after two different field running protocols. *J Strength Cond Res* 23: 1560–1565, 2009.
3. Boullosa, DA, Tuimil, JL, Alegre, LM, Iglesias, E, and Lusquiños, F. Concurrent fatigue and potentiation in endurance athletes. *Int J Sports Physiol Perform* 6: 82–93, 2011.
4. Chaouachi, A, Poulos, N, Abed, F, Turki, O, Brughelli, M, Chamari, K, Drinkwater, EJ, and Behm, DG. Volume, intensity, and timing of muscle power potentiation are variable. *Appl Physiol Nutr Metab* 36: 736–747, 2011.

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. Power-time, force-time, and velocity-time curve analysis of the countermovement jump: Impact of training. *J Strength Cond Res* 23: 177–186, 2009.
7. Denton, J and Cronin, JB. Kinematic, kinetic and blood lactate profiles of continuous and intraset rest loading schemes. *J Strength Cond Res* 20: 528–534, 2006.
8. Docherty, D and Hodgson, MJ. The application of postactivation potentiation to elite sport. *Int J Sports Physiol Perform* 2: 439–444, 2007.
9. Haff, GG, Whitley, A, McCoy, LB, O'Bryant, HS, Kilgore, JL, Haff, EE, Pierce, K, and Stone, MH. Effects of different set configurations on barbell velocity and displacement during a clean pull. *J Strength Cond Res* 17: 95–103, 2003.
10. Hansen, KT, Cronin, JB, and Newton, MJ. The effect of cluster loading on force, velocity, and power during ballistic jump squat training. *Int J Sports Physiol Perform* 6: 455–468, 2011.
11. Hardee, JP, Lawrence, MM, Utter, AC, Triplett, NT, Zwetsloot, KA, and McBride, JM. Effect of inter-repetition rest on ratings of perceived exertion during multiple sets of the power clean. *Eur J Appl Physiol* 112: 3141–3147, 2012.
12. Hardee, JP, Triplett, NT, Utter, AC, Zwetsloot, KA, and McBride, JM. Effect of inter-repetition rest on power output in the power clean. *J Strength Cond Res* 26: 883–889, 2012.
13. Hodgson, M, Docherty, D, and Robbins, D. Post-activation potentiation: Underlying physiology and implications for motor performance. *Sports Med* 35: 585–595, 2005.
14. Hopkins, WG, Marshall, SW, Batterham, AM, and Hanin, J. Progressive statistics for studies in sports medicine and exercise science. *Med Sci Sports Exerc* 41: 3–13, 2009.
15. Iglesias, E, Boullosa, DA, Dopico, X, and Carballeira, E. Analysis of factors that influence the maximum number of repetitions in two upper-body resistance exercises: Curl biceps and bench press. *J Strength Cond Res* 24: 1566–1572, 2010.
16. Khamoui, AV, Brown, LE, Coburn, JW, Judelson, DA, Uribe, BP, Nguyen, D, Tran, T, Eurich, AD, and Noffal, GJ. Effect of potentiating exercise volume on vertical jump parameters in recreationally trained men. *J Strength Cond Res* 23: 1465–1469, 2009.
17. Lawton, TW, Cronin, JB, and Lindsell, RP. Effect of interrepetition rest intervals on weight training repetition power output. *J Strength Cond Res* 20: 172–176, 2006.
18. Moir, GL, Mergy, D, Witmer, C, and Davis, SE. The acute effects of manipulating volume and load of back squats on countermovement vertical jump performance. *J Strength Cond Res* 25: 1486–1491, 2011.
19. Morana, C and Perrey, S. Time course of postactivation potentiation during intermittent submaximal fatiguing contractions in endurance- and power-trained athletes. *J Strength Cond Res* 23: 1456–1464, 2009.
20. Place, N, Maffiuletti, NA, Ballay, Y, and Lepers, R. Twitch potentiation is greater after a fatiguing submaximal isometric contraction performed at short vs. long quadriceps muscle length. *J Appl Physiol* 98: 429–436, 2005.
21. Rijkelijkhuizen, JM, de Ruiter, CJ, Huijng, PA, and Haan, A. Low-frequency fatigue, post-tetanic potentiation and their interaction at different muscle lengths following eccentric exercise. *J Exp Biol* 208 (Pt. 1): 55–63, 2005.
22. Rixon, KP, Lamont, HS, and Bemben, MG. Influence of type of muscle contraction, gender, and lifting experience on postactivation potentiation performance. *J Strength Cond Res* 21: 500–505, 2007.
23. Rodacki, AL, Fowler, NE, and Bennett, SJ. Vertical jump coordination: Fatigue effects. *Med Sci Sports Exerc* 34: 105–116, 2002.
24. Sale, DG. Postactivation potentiation: Role in human performance. *Exerc Sport Sci Rev* 30: 138–143, 2002.
25. Tillin, NA and Bishop, D. Factors modulating post-activation potentiation and its effect on performance of subsequent explosive activities. *Sports Med* 39: 147–166, 2009.
26. Tran, QT, Docherty, D, and Behm, D. The effects of varying time under tension and volume load on acute neuromuscular responses. *Eur J Appl Physiol* 98: 402–410, 2006.
27. Vuorimaa, T, Virlander, R, Kurkilahti, P, Vasankari, T, and Häkkinen, K. Acute changes in muscle activation and leg extension performance after different running exercises in elite long distance runners. *Eur J Appl Physiol* 96: 282–291, 2006.
28. Wilson, JM and Flanagan, EP. The role of elastic energy in activities with high force and power requirements: A brief review. *J Strength Cond Res* 22: 1705–1715, 2008.
29. Young, WB, Jenner, A, and Griffiths, K. Acute enhancement of power performance from heavy load squats. *J Strength Cond Res* 12: 82–84, 1998.