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ORIGINAL INVESTIGATION

The Effects of Cluster-Set and Traditional-Set Postactivation Potentiation Protocols on Vertical Jump Performance

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Purpose: To compare the effects of 2 postactivation potentiation (PAP) protocols using traditional-set or cluster-set configurations on countermovement jump performance. ***Methods:*** Twenty-six male basketball players completed 3 testing sessions separated by 72 hours. On the first session, subjects performed barbell jump squats with progressively heavier loads to determine their individual optimum power load. On the second and third sessions, subjects completed 2 PAP protocols in a randomized order: 3 sets of 6 repetitions of jump squats using optimum power load performed with either a traditional-set (no interrepetition rest) or a cluster-set (20-s rest every 2 repetitions) configuration. After a warm-up, countermovement jump height was measured using a force platform before, 30 seconds, 4 minutes, and 8 minutes after completing the PAP protocols. The following kinetic variables were also analyzed and compared: relative impulse, ground reaction force, eccentric displacement, and vertical leg-spring stiffness. ***Results:*** Across both conditions, subjects jumped lower at post 30 seconds by 1.21 cm, and higher in post 4 minutes by 2.21 cm, and in post 8 minutes by 2.60 cm compared with baseline. However, subjects jumped higher in the cluster condition by 0.71 cm (95% confidence interval, 0.37 to 1.05 cm) in post 30 seconds, 1.33 cm (95% confidence interval, 1.02 to 1.65 cm) in post 4 minute, and 1.64 cm (95% confidence interval, 1.41 to 1.88 cm) in post 8 minutes. The superior countermovement jump performance was associated with enhanced kinetic data. ***Conclusions:*** Both protocols induced PAP responses in vertical jump performance using jump squats at optimum power load. However, the cluster-set configuration led to superior performance across all time points, likely due to reduced muscular fatigue.

Keywords: ballistic exercises, basketball, explosiveness, neuromuscular capabilities, power

Postactivation potentiation (PAP) refers to a short-term improvement in physical performance as a result of a previous conditioning activity.[1] Commonly used as the final part of a warm-up routine,[2] PAP-inducing protocols have the potential to enhance athletic activities such as jumping, throwing, and sprinting.[3] Many factors mediate the PAP effect,[4] including gender,[5] training background, type, and specificity of the PAP conditioning activity and the athletic activity.[5–9] A key variable that consistently influences the onset and degree of the PAP effects is the time interval between the PAP conditioning activity and the subsequent performance test.[10] Whereas the exact PAP onset time varies and depends on individual characteristics,[5,11,12] the majority of PAP studies have reported that a recovery interval of 4 to 11 minutes is required to elicit the largest PAP effect.[3,5,10] This selected recovery interval is of great importance in managing 2 concurrent effects resulting from the PAP protocol: PAP and fatigue, both of which follow different time courses.[4] At the completion of the PAP conditioning activity, both central (eg, inhibiting α-motoneuron activation, reduction of the supraspinal descending drive) and peripheral (eg, action potential failure, excitation–contraction coupling failure, or impairment of cross-bridge cycling) fatigue occurs, which overcomes the potentiation effects of the PAP protocol, thus leading to reduced performance.[13] However, as fatigue dissipates at a faster rate than potentiation, the potentiation effects can be realized at some point during the recovery period.[5,10] Hence, there is a delicate balance between fatigue and potentiation.

Whereas most protocols implement heavy loads (ie, >85% 1-repetition maximum [1-RM]) to induce a PAP effect, Dello Iacono and Seitz[8] recently proposed to use relatively lighter loads (ie, ~60% 1-RM) equal to an optimal power load (OPL)[14] as the conditioning activity. OPL are exercise specific and may largely vary in terms of absolute loads. However, Soriano et al[15] reported OPL of lower-body resistance exercises to be consistently lower (from ≥30% to ≤70% of 1-RM) than 85% of -1-RM. The rationale of implementing OPL in PAP protocol is 2 folds. First, an optimal load is individually prescribed to produce maximal power outputs. Second, by using the relatively lighter loads, less fatigue should be accumulated. These concurrent factors likely allow for greater potentiation effects in the subsequent activities.[4,13] This hypothesis was confirmed in the study of Dello Iacono and Seitz, where elite soccer players sprinted faster following a hip thrust PAP protocol using OPL loads, compared with the 85% of 1-RM loads.[8]

Another potential method to reduce the fatigue associated with the conditioning activity is through cluster sets[16]: the inclusion of short rest periods between repetitions within a given set. Cluster-set configuration is associated with the division of repetitions within a given set into small clusters (eg, 2–6) of repetitions (eg, 2–3) that are separated by brief rest periods (eg, 10–60 s). Cluster-set configuration allows subjects to maintain greater outputs of force, velocity, and mostly power at a given load when compared with traditional-set configuration, absent of any rest within a set.[17–22] Therefore, cluster-set training may represent a viable method for PAP protocols design. To date, only 2 studies compared PAP protocols using either a traditional or a cluster-set configuration[23,24] and both observed improved performance to a small extent (<2%) with the cluster condition. It should be noted, however, that both

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studies implemented heavier loads as the conditioning activity, which may lead to greater fatigue compared with OPL.

We hypothesize that PAP protocols using OPL together with the cluster-set configuration will minimize fatigue and optimize the potentiation effects. The purpose of this study is to compare a PAP protocol using jump squats with OPL performed in a cluster-set configuration to a traditional-set configuration on countermovement jump (CMJ) heights among professional male basketball players.

Methods

Subjects

A total of 26 male basketball players (aged 23.2 [5.1] y; height 189.3 [3.2] cm; body mass 88.2 [6.5] kg), members of the first (n = 12) and U19 (n = 14) teams of a professional basketball club, volunteered to participate in the study. The players had at least 6 years (range 6–11) of high-level practice and 5 years (range 5–8) of resistance training experience. Importantly, all subjects had at least 2 years (range 2–4) of resistance training experience involving OPL methodologies. Subjects trained 4 to 5 times per week for about 90 minutes and played one official match scheduled at midweek or over the weekend. Written informed consent was obtained after the subjects received an oral explanation of the purpose, benefits, and potential risks of the study. All procedures were conducted in accordance with the Declaration of Helsinki and approved by the ethics committee at the Academic College at Wingate.

Design

A randomized cross-over design was used to compare the effects of 2 PAP protocols employing the same conditioning activity (jump squats with OPL) but with different sets configurations (traditional and cluster) on subsequent vertical jump performance assessed by the CMJ test. Subjects completed one familiarization and 2 experimental sessions each including: a standardized warm-up and baseline CMJ assessment, either a traditional-set or a cluster-set PAP protocol and CMJ reassessment after 30 seconds, 4 minutes, and 8 minutes of passive recovery (see Figure 1 for the study layout).[10] The order in which the protocols were completed was counterbalanced and determined by block randomization (www.random.org). All tests were performed in the same facilities. Subjects completed the 2 protocols at the same time of the day (4:00–6:00 PM), ambient conditions (22.1°C [0.3]°C), and relative humidity (60% [1.8%]). To prevent fatigue, coaches and subjects were asked to refrain from intense training 24 hours prior to testing days and to avoid any training activity on the same day of the experimental sessions.

Optimum Power Load Assessment. One week prior to the study, subjects completed a familiarization session with the protocols and assessment procedures. On the same day, the OPL in the jump squat exercise was assessed for each athlete. First, the subjects performed an 8-minute general warm-up consisting of running drills and dynamic mobilization exercises. Then, jump squat warm-up sets with progressively heavier loads were performed. For the jump squat execution, subjects were asked to keep the barbell constantly pressed against the shoulders, to push against the ground as hard and fast as possible during the upward movement, and to jump in a ballistic manner as high as possible. To minimize variation in jump kinematic and kinetic patterns, jump squat depth was standardized using an adjustable rod placed on a tripod, and a manual goniometer was used to set depth to ~90° knee angle. The subjects squatted down until touching the rod with their glutes and kept the position for about 1 second before performing the jump squat. The OPL were assessed following the protocol described by Loturco et al,[14] on a Smith machine (Technogym Equipment, Bologna, Italy). Specifically, successive jump squats with increasing loads (ie, 10% of body mass added during each trial) were performed until a decrease in the mean propulsive power (MPP) output was observed. MPP only refers to the upward portion of the jump squat during which the barbell acceleration is greater than acceleration than gravity (ie, $a \geq 9.81$ m/s^2). Although other power-related outputs such as mean power and peak power may also be used for assessing OPL, MPP is preferably suggested as it limits biased underestimations of an individual's power capabilities when lifting light or medium loads.[25] The OPL were determined as the jump squat with the highest MPP values measured during the successive trials and then used to design the PAP protocols. The MPP measures were collected using a linear encoder (Chronojump, Barcelona, Spain) sampling at 1000 Hz and fixed to the bar of the Smith machine and computed using the commercial software provided by the manufacturer in conjunction with the device.

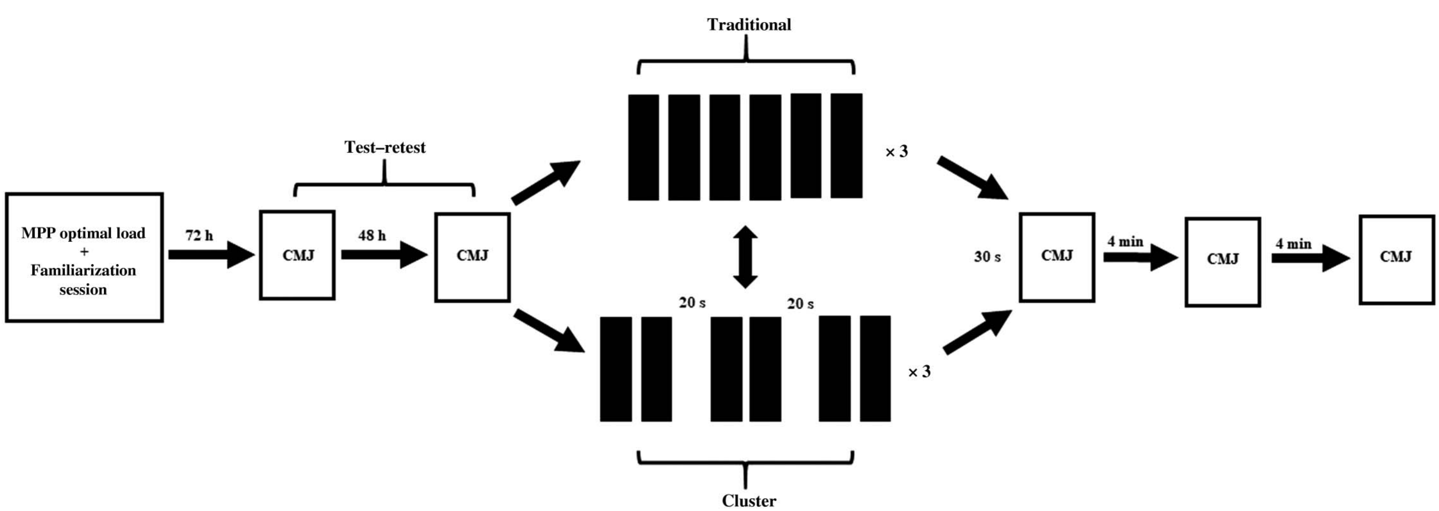

Figure 1 — Schematic representation of the study design. CMJ indicates countermovement jump; MPP, mean propulsive power.

Finally, body mass normalized MPP outputs (relative power, W/kg) were used for data analysis purpose. The normalized MPP scores measured during the OPL assessment were 9.9 (1.1) W/kg.

Vertical Jump Assessment. Vertical jump capability was assessed by a CMJ test.[26] Starting position was stationary, erect, with knees fully extended and hands kept on the hips to avoid any influence of arms' movement. Subjects then squatted down to a self-selected height before beginning a forceful upward motion. They were instructed to jump as high as possible, and verbal encouragement was provided during the jumps. The CMJs vertical ground reaction forces (GRF) outputs were collected by stationary force plate (Kistler Biomechanics, Winterthur, Switzerland). Sampling frequency was set at 500 Hz, and the signal was electronically processed and amplified by a Kistler amplifier (model No 9681A). The GRF data were used to define some key instants of the CMJ such as (1) start—defined as the instant in which the GRF went below a threshold value of 5% relatively to the subjects' body mass and (2) end—defined as the instant in which the GRF went below the threshold value of 0 N. The vertical jump performance (cm) was determined by the vertical velocity of the center of mass at takeoff calculated by double integrating the vertical GRF through the impulse–momentum method.[27] The vertical velocity signal was also used to plot the center of mass position throughout the whole movement. From this, the eccentric displacement (S_{ecc}) was calculated from the initial downward movement to the lowest point during the downward phase of the CMJ. A spring-mass model was used to analyze the vertical leg-spring stiffness (k_{vert}). This is defined as the ratio of the peak force in the spring and the displacement of the spring at the instant that the leg spring is maximally compressed. k_{vert} was calculated according to Comyns et al's[28] method, by dividing the GRF_{peak} by the S_{ecc}. Finally, the relative vertical impulse (I) was also calculated from the force–time curves as the ratio between the total impulse produced during the CMJ and the impulse due to body mass alone. Subjects completed a baseline assessment consisting of 3 CMJs (the best result used for the analysis) with approximately 45-second rest in-between while only a single CMJ trial was repeated per each post-PAP time point. A single researcher administered all the tests thus minimizing potential effects due to the provided instructions.

Postactivation Potentiation Protocols. The PAP protocols consisted of jump squats loaded with OPL performed either in a traditional manner (3 sets of 6 repetitions) or as a cluster-set configuration (3 sets of 6 repetitions with 20-s rest every 2 repetitions). The rest period between sets in both protocols was 2 minutes. Subjects were asked to assume the same position as the one described for the OPL assessment procedures. The individual subjects' MPP outputs produced during both PAP protocols were fully monitored and recorded with the linear encoder and the associated commercial software described above. A researcher and 1 coach supervised all exercises and provided verbal encouragement. The duration of the protocols, including the rest intervals and duration of the sets, was 5 minutes 23 (4) seconds and 7 minutes 32 (7) seconds for the traditional and cluster set, respectively.

Statistical Analysis

All data are presented as mean (SD) and 95% confidence interval (CI). Normality of the absolute data was investigated using the Shapiro–Wilk test, and skewness and kurtosis values smaller than 2 served as indication of normality.[29] The intraday reliability of the 3-baseline CMJ in day 2 and day 3 was examined using the coefficient of variation (both absolute and percentage). A coefficient of variation <5% is considered a cutoff value for high reliability.[30] The interday reliability of the highest CMJ in day 2 and day 3 was examined using Pearson correlation with 0.1, 0.3, 0.5, 0.7, and 0.9 interpreted as small, moderate, large, very large, and nearly perfect. To complement the correlation analysis, the level of agreement in CMJ pretest performance between day 1 and day 2 was examined with Bland–Altman bias estimates. The 95% CI of the mean difference was used to determine systematic bias. To compare the effects between the traditional-set and cluster-set configurations, a 2-way repeated-measures analysis of variance of the absolute scores across all time points, was used (2 conditions × 4 time points [baseline, post 30 s, post 4 min, and post 8 min]). This analysis was conducted 4 times for the following variables: jump height, I, GRF_{peak}, S_{ecc}, and k_{vert}.

In addition, the primary outcome, CMJ height, was also analyzed by comparing the change scores of the post–pre differences between conditions. That is, the posttests values of each participant were subtracted from the baseline values within a given condition (eg, post 30 s—baseline). Then, these differences were compared between conditions using a 2-way repeated-measures analysis of variance (2 conditions × 3 time points [post 30 s, post 4 min, and post 8 min]). This allowed to examine differences between conditions while also accounting for baseline. The power outputs of each athlete, monitored during both PAP protocols, were divided by the relative mean propulsive power (MMP REL) recorded during the OPL assessment to provide an estimate of fatigue elicited by the 2 protocols. Differences were considered significant at $P < .05$; however, for the most part, 95% CI were reported instead of P values to prevent dichotomous interpretation of the results and to allow for a more nuanced and qualitative interpretation of the data.[31,32] If significant main effects and/or interactions were found, then paired t tests with Bonferroni (Holms) post hoc analysis were conducted. All statistical analyses were conducted using Jamovi (version 0.92; Newcastle, United Kingdom).

Results

All data presented normal distribution. No differences were found for body mass between the 2 experimental sessions (88.1 [4.3] kg vs 88.4 [3.7] kg). The absolute scores of the individual intraday variation between the 3 baseline CMJs in days 2 and 3 were 0.6 cm (95% CI, 0.52 to 0.67 cm) and 0.7 cm (95% CI, 0.67 to 0.74 cm), respectively. The coefficient of variation (%) in days 2 and 3 of the intraday CMJs were 1.01% (95% CI, 0.97% to 1.07%) and 1.18% (95% CI, 1.12% to 1.24%), respectively, demonstrating high reliability. The correlation between the CMJ baseline of days 2 and 3 was nearly perfect ($r = .99$, $P < .001$). Bland–Altman analysis observed a small bias of 0.3 cm (95% CI, −1.4 to 2.1 cm) favoring the traditional condition, with only 1 subject falling outside the 95% limits of agreement, indicating good agreement between the 2 sessions. Across both conditions, a similar pattern emerged in which mean performance decrements were observed in post 30 seconds compared with baseline, followed by performance increments in post 4 minutes and post 8 minutes compared with baseline (Table 1 and Figure 2). Statistically significant interactions were identified between conditions and time for absolute jump height ($F_{3,75} = 47$, $P < .001$), I ($F_{3,75} = 17.5$, $P < .001$), GRF_{peak} ($F_{3,75} = 20$, $P < .001$; S_{ecc} ($F_{3,75} = 8$, $P < .001$), and k_{vert} ($F_{3,75} = 30$, $P < .001$), in which the cluster-set condition led to more favorable responses (see Table 1 for absolute mean values and differences between conditions).

The change score analysis revealed a statistically significant interaction between conditions and time for CMJ height

Table 1 Absolute Mean (SD) Values of All Variables, Across All Time Points, for Both Conditions

	Time points			
	Baseline	Post 30 s	Post 4 min	Post 8 min
CMJ, cm				
Cluster	60 (8)	59.1 (8)	62.8 (9)	63.4 (9)
Traditional	60.3 (8)	58.8 (8)	61.9 (8)	62.1 (8)
95% CI	–0.1 to 0.7	–0.1 to 0.8	–0.6 to 1.4	1 to 1.6
I, N/s				
Cluster	1.57 (0.13)	1.52 (0.12)	1.64 (0.13)	1.65 (0.14)
Traditional	1.57 (0.14)	1.49 (0.12)	1.60 (0.14)	1.61 (0.14)
95% CI	–0.03 to 0.09	0.02 to 0.04	0.02 to 0.04	0.03 to 0.05
GRF_{peak}, N				
Cluster	1855 (221)	1798 (212)	1937 (221)	1957 (217)
Traditional	1844 (226)	1756 (212)	1884 (214)	1891 (211)
95% CI	1 to 21	27 to 57	36 to 70	50 to 83
S_{ecc}, m				
Cluster	0.32 (0.02)	0.32 (0.02)	0.31 (0.02)	0.31 (0.02)
Traditional	0.32 (0.02)	0.33 (0.03)	0.32 (0.02)	0.32 (0.02)
95% CI	–0.004 to 0004	–0.001 to 0.01	0.003 to 0.009	0.007 to 0.01
K_{vert}, kN/m				
Cluster	5.8 (0.6)	5.6 (0.6)	6.1 (0.6)	6.3 (0.6)
Traditional	5.8 (0.6)	5.4 (0.64)	5.9 (0.65)	5.9 (0.63)
95% CI	–0.05 to 0.003	0.3 to 0.13	0.22 to 0.34	0.32 to 0.43

Abbreviations: CI, confidence interval; CMJ, countermovement jump; GRF_{peak}, peak ground reaction force; I, relative impulse; k_{vert}, vertical leg-spring stiffness; S_{ecc}, eccentric displacement. Note: The 95% CI of the differences between conditions are attached.

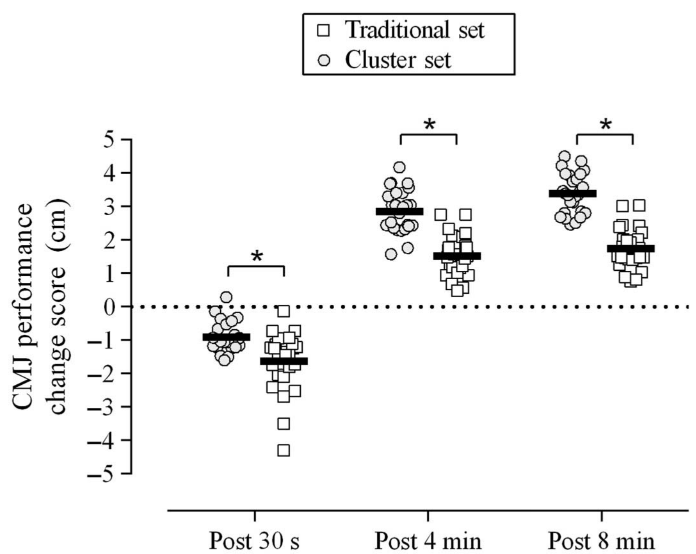

Figure 2 — Individual change scores relative to baseline. Each dot denotes an individual score. The horizontal lines denote mean group responses. CMJ indicates countermovement jump. *Statistically significant differences between conditions.

($F_{2,50} = 18.6$, $P < .001$). Although at post 30 seconds, no differences were found on average between conditions (0.71 cm [95% CI, 0.37 to 1.05 cm]), jump height was higher following the cluster set compared with the traditional condition at both post 4 minute and post 8 minute time points by 1.33 cm (95% CI, 1.02 to 1.65 cm) and 1.64 cm (95% CI, 1.41 to 1.88 cm), respectively (Figure 2). Finally, subjects were able to maintain 10% points higher power outputs (95% CI, 8% to 12%) relative to their MMP REL during the cluster set (9.4 [1.1] W/kg; 95% [4%]) compared with the traditional set (8.5 [1] W/kg; 85% [3%]).

Discussion

In this study, we examined the potentiation effects of 2 PAP protocols on vertical jump performance. Subjects completed either a traditional-set or a cluster-set configuration PAP protocol using jump squats with OPL. Two main findings emerged. First, and aligned with our hypothesis, the cluster-set configuration led subjects to jump higher compared with the traditional-set configuration across all posttest measures. Second, both protocols led to comparable time-course effects on jumping performance relative to baseline: reductions in CMJ heights measured at post 30 seconds, followed by enhancements in CMJ heights measured at post 4 minutes and post 8 minutes.

The main finding of this study was the superior CMJ performance across the 3 posttests following the cluster set compared with the traditional-set configuration. We assume that the windows of rest embedded within the cluster-set PAP protocol induced less fatigue, thereby allowing potentiation to manifest to a greater extent (Table 1 and Figure 2). This assumption is supported by 2 main observations. First, subjects were able to maintain 95% of their relative MPP values during the cluster sets (9.4 [1.1] W/kg) compared with 85% in the traditional-set condition (8.5 [1] W/kg). Second, although performance decrement was present in both cluster-set and traditional-set configurations at post 30 seconds, the decline was sharper in the traditional-set protocol (Figure 2). The mechanical responses associated to the CMJ at the posttests confirm these assumptions (Table 1). Following the cluster-set protocol, subjects were able to generate greater vertical impulses that, coupled with higher GRF_{peak} and K_{vert}, and shorter S_{ecc}, indicate enhanced neuromuscular efficacy.[33] These observations point to reduced fatigue and concurrent enhanced mechanical responses, which we presume are key mediators explaining the superior CMJ performance in favor of the cluster-set protocol. Aligned with this finding, 2 other studies reported that cluster sets led to superior performance compared with traditional-set configuration (albeit using heavier loads [>85% 1-RM]).[23,24] This is in addition to the accumulating body of evidence showing that fatigue can be minimized, and power outputs maintained, by using cluster-set configurations with 20- to 40-second rest intervals between repetitions of ballistic exercises, similar to those used in the current study.[19,21,22,34] In a training context, considering that the only cost of the cluster-set configuration was the addition of 2 minutes to complete the protocol, the clear and meaningful benefits seem well worthwhile.

In addition to cluster sets, OPL are also a viable training strategy that can reduce muscular fatigue and accordingly, amplify PAP effects. Although OPL have been extensively studied in the sport science domain as a training strategy,[35] the topic remains relatively unexplored as an approach to stimulate PAP effects. To our knowledge, the only other study in addition to the current one that examined optimal power loads in PAP protocols was conducted by Dello Iacono and Seitz.[8] The authors reported 5- and 10-m sprint time performances improvements following a PAP protocol implementing the hip thrust exercise with OPL. The similar effects observed in our study can be explained by mechanical pathways and methodological considerations. From a mechanical perspective, the prerequisite of ballistic jump squat is that body mass is accelerated throughout the entire movement without a braking phase. The extended duration of positive acceleration facilitates greater force and power outputs.[36,37] These greater mechanical outputs likely underpin the potentiation effects on jump performance.[11] From a methodological perspective, the biomechanical similarity between the conditioning exercises and the subsequent athletic task used in this study increased the likelihood of greater PAP effects. In fact, high-movement specificity and the associated kinematic and kinetic variables seem to play a favorable role in optimizing the potentiation effects. Another advantage of using OPL with PAP protocols, is that the selected loads are individually determined by the subjects' force–velocity relationships and power outputs rather than relative loads derived from the 1-RM. This allows for a more accurate mechanical representation of an athlete's individual capabilities, which presumably mediates the degree of performance improvements following a potentiating stimulus.[11,12] Collectively, these results suggest that the OPL approach is a viable loading strategy in PAP protocols, which can be used in addition to—or instead of—the commonly implemented heavier loads (>85% 1-RM).

The time course of the effects induced by the PAP protocols of this study is consistent with the PAP literature: transitional fatigue at the PAP protocol completion, followed by potentiation after 4 minutes of rest.[1,4,5,10] In this study, subjects jumped ~3% lower at post 30 seconds compared with baseline, whereas CMJ heights increased by 3.7% and 4.2% at post 4 minutes and post 8 minutes, respectively. This finding is aligned with the fatigue–potentiation relationship[4] and the importance of an appropriate time interval between the completion of the PAP protocol and the beginning of the subsequent exercise.

This study has a number of limitations worthy of discussion. First, the absence of other experimental conditions in which subjects would have completed the traditional and cluster set using heavier loads (>85% 1-RM), narrows what can be concluded from this study. We also did not conduct an a priori power analysis, but rather, relied on a convenient sample of subjects. In attempt to overcome this limitation, we implemented a within-subjects design and controlled for a large number of confounding variables, such as diet, time of the day, and more.

Practical Applications

Coaches should consider implementing cluster-set PAP protocols using jump squat loaded with OPL as a training strategy to enhance vertical jump performance. Cluster-set configurations seem to exploit the PAP effect by reducing fatigue and by enhancing the mechanical responses underpinning jumping performance. Utilizing cluster-set configuration is a useful approach that only takes a few additional minutes to complete; a negligible cost in view of the performance augmentations observed in this study.

Conclusions

We observed that professional basketball players jumped higher in the cluster-set condition across all time points compared with the traditional-set configuration, absent of rest within the sets. This effect likely stems from enhanced mechanical responses and reduced muscular fatigue. Although more research is needed to verify these findings, these results have practical benefits.

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