The effects of cluster-set and traditional-set post activation potentiation protocols on vertical jump performance

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Abstract

Purpose. To compare the effects of two post-activation potentiation (PAP) protocols using traditional or cluster-set configurations on countermovement jump (CMJ) performance. **Methods.** Twenty-six male basketball-players completed three 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 loads (OPL). On the second and third sessions, subjects completed two PAP protocols in a randomized order: three sets of six repetitions of jump squats using OPL performed with either a traditional (no inter-repetition rest) or a cluster-set (20s rest every two repetitions) configuration. After a warm up, CMJ height was measured using a force platform before, 30 s, 4-min, and 8-min 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-30s by 1.2**1** cm, and higher in post-4 **min** by 2.2**1** cm and in post-8 min by 2.6**0** cm compared to baseline. However, subjects jumped higher in the cluster condition by 0.71 cm (95%CI: 0.37, 1.05 cm) in post-30 s, 1.33 **cm** (95%CI: 1.02, 1.65 **cm**) in post-4 min, and 1.64 **cm** (95%CI: 1.41, 1.88 **cm**) in post-8 min. The superior CMJ performance was associated with enhanced kinetic data. **Conclusions**. Both protocols induced PAP responses in vertical jump performance using jump squats at OPL. 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

Introduction

Post-activation 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 4-11 min is required in order to elicit the largest PAP effect.[3,5,10] This selected recovery interval is of great importance in managing two 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 (e.g., inhibiting **α**-motoneuron activation, reduction of the supraspinal descending drive) and peripheral (e.g., 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, since 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 (i.e., >85% 1RM) to induce a PAP effect, Dello Iacono and Seitz[8] recently proposed to use relatively lighter loads (i.e., ~ 60% 1RM) 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

1RM) than 85% of 1RM. The rationale of implementing OPL in PAP protocol is twofold. 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 to the 85% of 1RM 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 (e.g., 2-6) of repetitions (e.g., 2-3) that are separated by brief rest periods (e.g., 10-60 s). Cluster-set configuration allows subjects to maintain greater outputs of force, velocity, and mostly power at a given load when compared to 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 two 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 studies implemented heavier loads as the conditioning activity, which may lead to greater fatigue compared to OPL.

In view of the above, 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 CMJ heights among professional male basketball players.

Methods

Subjects

Twenty-six male basketball players (age 23.2±5.1 years; 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 six years (range: 6-11) of high-level practice and five years (range: 5-8) of resistance training experience. Importantly, all subjects had at least two years (range: 2-4) of resistance training experience involving OPL methodologies. Subjects trained four to five times per week for about 90 min and played one official match scheduled at mid-week 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 Helsinki Declaration and approved by the Institution's Ethics Committee.

Design

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

*****Figure 1 about here*****

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 were assessed for each athlete. First, the subjects performed an 8 min 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 ~90º knee angle. The subjects squatted down until touching the rod with their glutes, and kept the position for about 1 s before performing the jump squat. The OPL were assessed following the protocol described by Loturco et al.,[14] on a Smith machine (Technogym Equipment, Italy). Specifically, successive jump squats with increasing loads (i.e., 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 (i.e., $a \geq 9.81$ 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. 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: (i) start – defined as the instant in which the GRF went below a threshold values of 5% relatively to the subjects' body mass, (ii) 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 centre 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 centre 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's et al.,[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 three CMJs (the best result used for the analysis) with approximately 45 s 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.

Post activation 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 rests every 2 repetitions). The rest period between sets in both protocols was 2 min. 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 one coach supervised all exercises and provided verbal encouragement. The duration of the protocols, including the rest intervals and duration of the sets, was 5 min 23 s ± 4 s and 7min 32 s ± 7 s for the traditional and cluster-set, respectively.

Statistical Analysis

All data are presented as means ± standard deviation (SD) and confidence interval (95% 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 intra-day reliability of the three baseline CMJ in day 2 and day 3 was examined using the Coefficient of Variation (both absolute and percent). A CV < 5% is considered a cut-off value for high reliability.[30] The inter-day 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 pre-test 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 and cluster-set configurations, a two-way repeated measures Analysis of Variance (ANOVA) of the absolute scores across all time points, was used (two conditions x four time points [baseline, post-30 s, post-4 min and post-8 min]). This analysis was conducted four times for the following variables: jump height, I, GRF_{peak}, S_{ecc} and k_{vert}.

Additionally, the primary outcome, CMJ height, was also analyzed by comparing the change scores of the post-pre differences between conditions. That is, the post-tests values of each participant were subtracted from the baseline values within a given condition (e.g., post-30 s – baseline). Then, these differences were compared between conditions using a two-way repeated measures Analysis of Variance (two conditions x three 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 individual athletes' power outputs monitored during each PAP protocol were divided by the MMP REL recorded during the OPL assessment to provide an estimate of fatigue elicited by the two protocols. Differences were considered significant at $p < 0.05$, however, for the most part, 95% CI were reported instead of p values in order 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).

Results

All data presented normal distribution. No differences were found for body mass between the two experimental sessions (88.1±4.3 kg vs. 88.4±3.7 kg). The absolute scores of the individual intra-day variation between the three baseline CMJs in day 2 and 3 were 0.6 cm (95% CI: 0.52, 0.67 cm) and 0.7 cm (95% CI: 0.67, 0.74 cm), respectively. The CV% in day 2 and 3 of the intra-day CMJs were 1.01% (95% CI: 0.97, 1.07 %) and 1.18% (95% CI: 1.12, 1.24 %), respectively, demonstrating high reliability. The correlation between the CMJ baseline of day 2 and 3 was nearly perfect ($r = 0.99$, $p < 0.001$). Bland-Altman analysis observed a small bias of 0.3 cm (95% CI: -1.4, 2.1 cm) favoring the traditional condition, with only one subject falling outside the 95% limits of agreement, indicating good agreement between the two sessions. Across both conditions a similar pattern emerged in which mean performance decrements were observed in post-30 s compared to baseline, followed by performance increments in post-4 min and post-8 min compared to baseline (See Table 1 and Figure 2). Statistically significant interactions were identified between conditions and time for absolute jump height ($F_{(3, 75)} = 47$, $p < 0.001$), I ($F_{(3, 75)} = 17.5$, $p < 0.001$), GRF_{peak} ($F_{(3, 75)} = 20$, $p < 0.001$), S_{ecc} ($F_{(3, 75)} = 8$, $p < 0.001$) and k_{vert} ($F_{(3, 75)} = 30$, $p < 0.001$), 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 ($F_{(2, 50)} = 18.6$, $p < 0.001$). While at post-30 no differences were found on average between conditions (0.71 cm [95% CI: 0.37, 1.05 cm]), jump height was higher following the cluster-set compared to the traditional condition at both post-4 min and post-8 min time points by 1.33 cm (95% CI: 1.02, 1.65 cm) and 1.64 cm (95% CI: 1.41, 1.88 cm), respectively (Figure 2). Finally, subjects were able to maintain 10 percentage points higher power outputs (95% CI: 8, 12%) relative to their MMP REL during the cluster set (9.4±1.1 W/kg; 95±4%) compared to the traditional-set (8.5±1 W/kg; 85±3%).

*****Table 1 and Figure 2 about here*****

Discussion

In this study we examined the potentiation effects of two 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 to the traditional-set configuration across all post-test measures. Second, both protocols led to comparable time-course effects on jumping performance relative to baseline: reductions in CMJ heights measured at post-30 s, followed by enhancements in CMJ heights measured at post-4 and post-8 min.

The main finding of this study was the superior CMJ performance across the three post-tests following the cluster-set compared to 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 two 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 to 85% in the traditional-set condition (8.5±1 W/kg). Second, while performance decrement was present in both cluster-set and traditional-set configurations at post-30 s, the decline was sharper in the traditional-set protocol (Figure 2). The mechanical responses associated to the CMJ at the post-tests 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, two other studies reported that cluster sets led to superior performance compared to traditional-set configuration (albeit using heavier loads (> 85%1RM)).[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 s 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 two minutes to complete the protocol, the clear and meaningful benefits seem well worthwhile.

In addition to cluster-sets, OPL is also a viable training strategy that can reduce muscular fatigue and accordingly, amplify PAP effects. While 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 m 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 pre-requisite 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 favourable 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 1RM. 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% 1RM).

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 min of rest.[1,4,5,10] In this study, subjects jumped ~3% lower at post-30 s compared to baseline while CMJ heights increased by 3.7% and 4.2% at post-4 min and post-8 min, 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 suffers from a number of limitations worthy of discussion. First, the absence of other experimental conditions in which subjects would have completed the traditional-set and cluster-set using heavier loads (>85% 1RM), 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.

Conclusion

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

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Figure Captions

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

Figure 2. Individual change scores relative to baseline. Each dot denotes an individual score. The horizontal lines denote mean group responses. Asterisk (*) denotes statistically significant differences between conditions.