International Journal of EXERCISE SCIENCE

Original Research

The Effect of Set Configuration and Load on Post-Activation Potentiation on Vertical Jump in Athletes

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ABSTRACT

International Journal of Exercise Science 14(4): 902-911, 2021. The aim of this study was to compare the effect of post-activation potentiation (PAP) on countermovement jump (CMJ) using different set configurations and loads on conditioning activity (CA) in highly trained athletes. Sixteen national level swimmers participated in this study and performed a total of six visits to the laboratory. The first session was used for familiarization, the second session was utilized to determine five repetitions maximum (RM) in the half squat (HS), and the following four visits consisted of four CA protocols performed in a counterbalanced order. Two CAs were performed as traditional sets (TS) with sequential repetition, with different load, which involved one set of five repetitions at 100% (TS100) or 65% of 5 RM load (TS65). Additionally, two CAs included one set of five repetitions with intraset rests, 30 second inter-repetition rest (IRR), with both relative loads (IRR100 and IRR65). Countermovement jump height was measured at baseline, immediately after the CA, and every two-minutes until twelve-minutes. Significantly faster peak and mean barbell velocity was observed for the CAs with lower relative loads ($p < 0.05$). When evaluating the best result at individual time point of CMJ height after the CA, TS100 improved CMJ performance (ES = 0.38, $p = 0.028$, $\Delta\% = 4.8 \pm 7.3$). Thus, set configuration using IRR does not promote PAP in the current study and TS with a high-load should be adopted for an acute improvement in CMJ for highly trained athletes.

KEY WORDS: Fatigue, performance, team sport, youth

INTRODUCTION

Post-activation potentiation (PAP) is an acute response in which an improvement of force and power development is observed after performing a conditioning activity (CA) with movement similarity (4, 8, 9). The main physiological rationale explaining the PAP response is related to the ability of the CA to impact the neural activation via an increase in higher threshold motor unit recruitment (30). Although a potentiation effect is produced, the CA simultaneously promotes muscle fatigue that can reduce acute performance (22, 25). Thus, the relationship of volume, intensity (load), rest interval between the CA and the main activity, and training status of the subjects should be considered when applying a PAP strategy (22-24). For example, a meta-analysis by Seitz and Haff (22) revealed that training status and strength level moderate the PAP response, as stronger individuals elicit a greater PAP response in a shorter time frame (5-7 minutes) after the CA than their weaker counterparts (≥ 8 minutes). Furthermore, the authors revelated the influence of the depth of a squat with a superior effect of half squat (ES = 0.58) than a deeper depth (ES = 0.25) because likely induces less fatigue (22).

Thereby, the optimal strategy to structure the CA in order to maximize the PAP response is the one that minimizes fatigue and maximizes the potentiation. In this sense, a set configuration with inter-repetition rest (IRR) or cluster sets incorporated within the CA might be a viable alternative to promote mechanical tension with less metabolite accumulation (15, 18, 27). The use of IRR or cluster sets may maintain movement velocity throughout sets when compared to traditional sets (TS) without intra-set rest (18). In a previous study, Boullosa et al. (2) reported greater peak power output one minute after a CA when using a 30 second IRR protocol, while the TS protocol only observed improvements nine minutes after the CA. This finding aligns with Nickerson et al. (16) who observed faster 20-meter sprint times ten minutes after a protocol of three repetitions with 30 seconds of IRR. However, the protocol with 60 seconds IRR promoted greater movement velocity within the CA (16).

When utilizing traditional resistance exercises as a CA, high-loads are generally recommended to promote PAP due to increased recruitment of higher threshold motor units that innervate Type II muscle fibers (22). However, similar movements performed with moderate-loads in an explosive manner (maximal intended concentric contraction), may also activate higher threshold motor units (22). Furthermore, moderate-load CAs were previously considered to be a favorable alternative to high-load CAs, especially in weaker subjects, due to a reduction in fatigue (22, 29). Wilson et al. (29) found that moderate-loads can potentiate to a greater extent versus high-loads, revealing a divergent finding in the literature. Similarly, CA which utilize IRR allow repetitions to be performed at consistently higher velocities, which may stimulate a PAP response in a subsequent performance activity. Due to the reduced fatigue associated with IRR, it might be that the time frame between CA and the maximal performance could be reduced when the CA employs this set configuration (2, 18). Therefore, the aim of the present study was to compare the effect of different set configurations (IRR vs. TS) with different loads (moderate vs. high) on countermovement jump performance and the strength level effects. It was hypothesized that set configurations with IRR would attenuate fatigue and promote PAP in a shorter time period after the CA. Additionally, it was hypothesized that faster repetitions performed with moderate-loads would be able to promote PAP similarly to high-load protocols. Lastly, it is to be expected that strongest individuals exhibited a grater PAP effect.

METHODS

Participants

Sixteen swimmers of the Fluminense Football Club (Table 1) participated in this study. All athletes competed at the national level, were engaged in resistance training (RT) for at least one year, and were familiarized with the CMJ as part of their existing training program (10). Additionally, athletes were in the competitive season and performed dry-land RT specific for power/strength development, which involved exercises performed with maximal relative velocity. For the swim training during the period of the study, training frequency varied between seven to nine sessions per week with a mean weekly volume of 43,000 to 51,000-m. In their RT routine, complex training that combined the HS with plyometric exercises (including the CMJ) were commonly used, and all dry-land RT sessions were performed before swimming training. Throughout the study, the four protocols replaced the RT sessions and athletes were instructed to not perform their usual dry-land RT sessions between the four experimental protocols. Thus, all experimental sessions were performed before swimming training and were not confounded by normal regimented RT routines.

Athletes with musculoskeletal injuries and those using ergogenic aids to optimize performance were excluded from this investigation. An informed parental consent was used for athletes aged under 18 years and those aged over signed an informed consent, detailing all procedures and potential risks.

This study followed the ethical procedures for experimental research with humans and has been approved by Research Ethics Committee of the Federal University of Rio de Janeiro (protocol number: 65731217.6.0000.5257) (14). The study has been conducted in accordance with the principles set forth in the Helsinki Declaration and according to the resolution 466/2012 of National Health Council and all participants signed informed consent prior to participating in the study.

Table 1. Sample characteristics.

Age (years)	Height (cm)	BM (kg)	Body fat (%)	5RM load (kg)	5RM load/BM
17.3 ± 2.1	175.7 ± 5.4	68.3 ± 6.7	7.0 ± 1.8	103.1 ± 18.3	1.50 ± 0.20

RM: repetition maximum, BM: body mass

Protocol

This was a repeated-measures study design, with crossover, in which all athletes performed all protocols in a random counterbalanced order. All testing procedures were performed at the same time of the day (i.e., 15:00-17:00), at the Fluminense Football Club, before swim training. Thus, no alteration was made in the swim training routine. Each subject performed a total of six visits, separated by at least 48 hours. The first visit was used for anthropometrics measurements and familiarization to the testing protocol. During the second visit, athletes were assessed in a five-repetition maximum (5-RM) test in the half squat (HS), and the following four visits consisted of four protocols with different set configurations and loads.

Familiarization: The first session consisted of a familiarization in which participants performed three sets of ten repetitions in an incremental protocol (50, 75, and 100% of 10-RM) with two-minute inter-set rest intervals. The load of 10-RM was used since the athletes were training in this repetition range and had previously performed 5-RM testing. During all sets, participants were instructed to perform at maximal concentric velocity which was monitored by a previously validated and reliable wireless device (Beast Sensor, Milan, Italy) attached to the bar (1). Previous research correlations between the Beast Sensor and linear transducer were *r* = 0.97-0.98, and reliability, measured by intraclass correlation coefficient (ICC), was 0.92-0.99 with standard error of the estimate of 0.04-0.05 $m \cdot s^{-1}$ (1) . An acquisition frequency of 50 Hz was used to evaluate repetition velocity throughout the investigation. Instantaneous feedback was provided by a computer monitor positioned in front of each subject.

5-RM test: The 5-RM load was determined in the HS on the second day, following similar procedures previously utilized for different repetition ranges (12, 19). Before starting the test, one set of 15 repetitions at maximal relative velocity with 50% of the load used in the athlete's RT routine was adopted as a warm-up. Three to five attempts with three to five minutes rest intervals between each attempt was used. The HS was performed with a standard free-weight barbell and participants were instructed to slow down during the eccentric phase, until approximately 90º of knee flexion as it has previously been recommended to promote PAP (22). To reduce the margin of error in testing, the following strategies were adopted: (a) standardized instructions were provided before the test, so the subject was aware of the entire routine involved with data collection, (b) participants were instructed on the technical execution of the exercises, (c) the researcher carefully monitored the position adopted during the exercises, (d) consistent verbal encouragement was given to motivate participants for maximal repetition performance, (e) the additional loads used in the study were previously measured with a precision scale (13, 19).

CMJ test: The vertical jump test was performed using a validated and reliable wearable device (VERT Classic; Mayfonk Athletic, Florida, USA) attached to the athlete's shorts (3). Previous research correlations between VERT and force plate were *r* = 0.95 (90% confidence interval = 0.93-0.97) with typical error of the estimate of 0.32, and yardstick was *r* = 0.93 (90% confidence interval = 0.90-0.95) with typical error of the estimate of 0.40 (3). Reliability measured by ICC was *r* = 0.90 (90% confidence interval = 0.87-0.94). Athletes performed two consecutive CMJs at eight time-points: baseline, immediately after each protocol (approximately 15 seconds after the CA), and every two minutes until twelve minutes. The highest jump of the two attempts at each time-point was recorded. The peak result for each protocol consisted of the best CMJ performed, regardless of the time-point. The inter-day reliability of the data was calculated using ICC of the CMJ, the baseline values were used and resulted in 0.884.

Experimental protocols: Before each protocol, a specific warm-up was performed with a non-ballistic HS which consisted of one set of ten repetitions at maximal relative velocity with 40% of the 5-RM load. Two minutes after the warm-up, a CMJ was performed to determine a baseline value followed by one of the four protocols, executed in a counterbalanced order. For each protocol, the HS was performed in a non-ballistic fashion as athletes were instructed to accelerate during the concentric phase of the movement, but reframe from jumping. Following each protocol, CMJs were performed every two minutes until 12 minutes as described above.
Two protocols were performed as traditional sets, but with different loads, which involved one set of five continuous repetitions at 100% (TS_{100}) or 65% (TS_{65}) of the 5-RM load. The other two

protocols involved one set of five repetitions with 30 second inter-repetition rest (IRR) with both loads (IRR_{100} and IRR_{65}). During the IRR protocols, athletes were oriented to position the bar in the rack and rest in a standing position. Considering the time to un-rack the bar, the athletes were instructed to un-rack the bar and start the movement during the last five seconds of the 30 second IRR. The athletes were encouraged to perform each repetition at maximal velocity in all experimental sessions. Average velocity ($m \cdot s^{-1}$) of each repetition was recorded, along with the average velocity of the five repetitions in each protocol. The inter-day reliability of the data was calculated using ICC of the velocity in the first repetition between TS100 and IRR100, resulting in 0.763 and between TS65 and IRR65 was 0.719.

Statistical Analysis

A power analysis conducted with G*POWER 3.1 (Universitat Kiel, Germany) determined that twelve participants were needed in the present study for a power of 0.80, with an effect size of 0.5 and an a = 0.05. Descriptive and parametric statistics were used for all analyses, with the results presented as mean ± standard deviation (SD), relative difference (Δ%) ± 90% confidence interval (CI). Initially, the Shapiro Wilk test was performed to verify data distribution. Then, three separate two-way ANOVAs with repeated measures were performed to identify the following: (1) within and between differences for repetition velocity (condition x repetition) and CMJ performance (condition x time-point), (2) interactions between conditions and peak CMJ height (i.e., best CMJ independent of the time-point), and (3) separated into two groups, which included strongest and weakest, and the within and between group interactions (group x time-point) were analyzed. When a significant effect was present, pairwise comparisons were performed using a Bonferroni correction when appropriate. An α-level of 0.05 was adopted for all inferential analysis. Hedges' g effect size (ES) and 90% CI was calculated for CMJ using differences between baseline and following each protocol divided by the pooled SD (21). Then, a correction factor was used based on the small sample size:

$$\text{Correction factor: } g = 1 - \frac{3}{4\,(n_1 + n_2 - 2) - 1}$$

Therefore, the corrected ES was the resulted of g multiplied by correction factor. The magnitude of effect size was rated according to Rhea (21) for recreationally trained participants, with RT experience between one to five years. The scales for determining ES was: < 0.35 trivial, 0.35-0.80 small, 0.80-1.50 moderate, and > 1.50 large.

RESULTS

According to the two-way ANOVA, there was a significant interaction between conditions and time-points (F = 1.992, p = 0.004), and a significant main effect for time (F = 10.847, p < 0.001). No significant pairwise interactions were observed between time-points after each protocol versus baseline (p > 0.05). However, when considering peak CMJ height on an individual basis, independent of rest interval length after the protocols, pairwise comparisons showed that the TS_{100} protocol significantly improved CMJ height versus baseline (ES = 0.38, p = 0.028) (Figure 1).

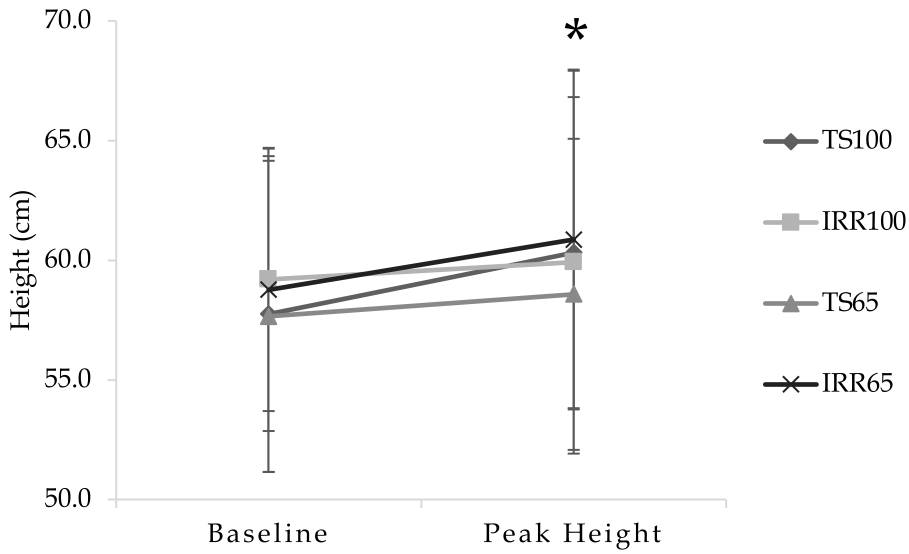

Figure 1. Peak height of countermovement jump test during a traditional set with (A) 100%, (B) 65%, (C) inter-repetition rest with 100%, and (D) inter-repetition rest with 65% of a five-repetition maximum. *Significant higher versus baseline at TS100.

According to the two-way ANOVA, the interaction among conditions and repetition velocity approached significance (F = 1.760, p = 0.058), yet there was a significant main effect for condition (F = 35.068, p < 0.001). Pairwise comparisons revealed significant differences for movement velocity, as lower relative loads of 65% possessed higher velocities versus heavier relative loads of 100% (p < 0.05). However, no significant pairwise interactions were observed for movement velocity between protocols (Figure 2).

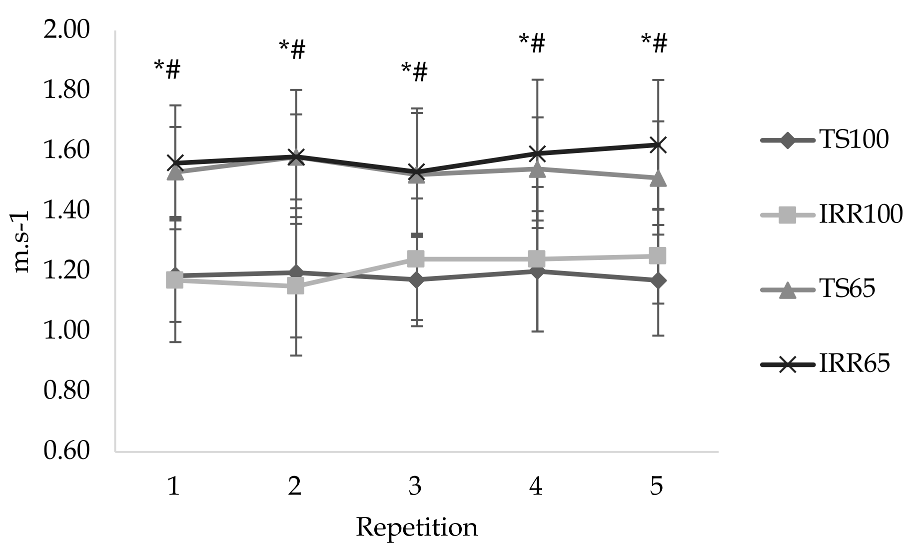

Figure 2. Repetition mean velocity during a traditional set with (A) 100%, (B) 65%, (C) inter-repetition rest with 100%, and (D) inter-repetition rest with 65% of a five-repetition maximum. *Significantly faster versus traditional set with 100%; #Significantly faster versus inter-repetition rest with 100%.

To understand the PAP response in TS_{100}, relative strength (5-RM/body mass) was calculated and used to separate subjects into two groups based on the median relative strength of 1.48 kg/kg body mass: below median (weakest: n = 8) and above median (strongest: n = 8) (Table 1). A two-way ANOVA showed a main effect for group (F = 16.195, p < 0.001), and pairwise comparisons revealed significantly greater peak CMJ for the strongest versus the weakest (p = 0.012) subjects, while no significant differences were observed at baseline (p = 0.184) between the groups (Table 2).

Table 2. Countermovement jump performance for the traditional protocol with 100% of a five-repetition maximum between the weakest versus strongest subjects.

	Strength (kg/BM)	Baseline (cm)	Peak (cm)	Δ% (90% CI)	ES (90% CI) rating
Weakest (n = 8)	1.36 ± 0.08	54.69 ± 4.05	55.73 ± 3.93	2.01 (1.81; 2.22)	0.26 (0.05; 0.46) trivial
Strongest (n = 8)	1.64 ± 0.18	60.81 ± 7.49	64.90 ± 5.25 *	7.49 (7.28; 7.69)	0.76 (0.56; 0.97) small

ES: effect size, CI: confidence interval, BM: body mass. * Significant differences between groups (p < 0.05).

DISCUSSION

The main finding of the present study was that the TS_{100} protocol induced PAP and improved CMJ performance, while the protocols using IRR did not. In the TS_{100}, CMJ improved about 4.8% (4.65-4.85, 90% CI) and showed a small ES of 0.38 (0.28-0.49, 90% CI) which can be considered a small magnitude, while other protocols showed trivial results. These findings align with previous research undertaken in athletes (6, 7, 28), and was in agreement with Seitz et al. (21) that suggested jump performance improvements were small in magnitude (ES = 0.31). This finding was especially attributed to the level of strength, as stronger athletes within the current sample showed significantly greater improvements versus weaker athletes.

In this study, both IRR protocols (IRR_{100} and IRR_{65}) were not effective at inducing PAP and increasing CMJ performance. Recent studies have reported that IRR protocols promote PAP (2, 16, 17). Nickerson et al. (16) showed that an IRR protocol of 30-seconds increased 20-meter sprint performance and CMJ height. The rationale for IRR is a reduction in fatigue and greater consistency in repetition velocity and power, allowing for greater expression of PAP. However, the present study demonstrated a divergent finding from Nickerson et al. (16), in which the TS_{100} protocol (5-RM) induced PAP and improved CMJ performance, suggesting that a more fatiguing stimulus with a high load can induce PAP. Thus, the ability to induce the PAP response appears to be dependent on several factors and a complex trade-off between potentiation and fatigue, which is likely very individualized. With traditional set schemes in which all repetitions of a set are performed continuously, the rest interval between the end of the set and ballistic activity is of paramount importance. In the current study, the rest interval following the TS_{100} condition prior to the CMJ was seven minutes, which corroborates with previous studies in trained subjects (21, 28).

Another interesting finding from the present study was that in the TS_{100} protocol, the stronger athletes improved CMJ performance to a significantly greater extent versus the weaker athletes. In a previous study, Suchomel et al. (26) showed that stronger subjects, with relative strength (1-RM load/body mass) of 2.1 ± 0.1 potentiate earlier and to a greater extent versus weaker subjects (1.6 ± 0.2 kg/body mass). A similar finding was observed by Seitz et al. (23) who reported an earlier PAP response in stronger subjects. In this study, athletes within the stronger group were also older (ranged 15-22 years old) and had trained longer than athletes in the weaker group (ranged 15-17 years old).

Considering the PAP response in athletes, Esformers and Bampouras (7) observed an improvement in CMJ after 3-RM squats performed at different depths (parallel vs. quarter) in semiprofessional rugby players. Otherwise, Seitz and Haff (22) suggests that deeper depth induce higher levels of acute fatigue because the longer time under tension. In this sense, the depth in the squat may change the results. Although all participants of this study were athletes at the national level, the strength level varied between them and this must be considered when using high load/deeper exercises to potentiate jump performance. The athletes within this study generally performed complex training that was similar to the TS_{100} protocol with a 5-RM and half squat. Therefore, the specificity of the PAP protocol to athletes regular training routine may warrant consideration in the design of future studies. In additional, this study examined the CMJ jump height of these athletes, but other test variables, such as power output or sprinting performance may reveal a divergent finding (16, 17).

Finally, protocols with moderate-loads were added in an attempt to improve performance via greater repetition velocity. In a previous study, Maloney et al. (11) demonstrated the effectiveness of ballistic exercise to recruit Type II fibers in absence of high-loads and with lower rates of fatigue, which can be considered a good strategy for a pre-activation stimulus. Crum et al. (5) did not observe improved performance in CMJs after a squat at 65% of 1-RM. In fact, the moderate-load protocols (65% of 5-RM) within the current investigation showed significantly greater average and peak repetition velocity versus the high-load protocol (100% of 5-RM). However, both protocols with the moderate-load used in this study (TS_{65} and IRR_{65}) did not elicit a PAP response, despite higher repetition velocities. This finding suggests that there might not be a relationship between the velocity of the pre-conditioning stimulus and the PAP response. Thus, when utilizing the half squat, higher-loads are a better strategy for athletes to elicit PAP, corroborating with previous investigations (22, 28, 29).

This study investigated only male athletes, which can be considered a limitation as these results cannot be generalized to non-athletes or women. As such, the current results should be considered for trained athletes with an extensive weight training background. Furthermore, despite the protocols that used an IRR did not promote PAP, a single traditional set of continuous repetitions with a 5-RM can be adopted for an acute CMJ improvements in highly trained athletes and a beneficial PAP response may occur in stronger athletes.

ACKNOWLEDGEMENTS

The authors are grateful to the Fluminense Football Club and the athletes for their participation and contribution to sports science.

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