Effect of volume on eccentric overload-induced post-activation potentiation of jumps

Abstract

Purpose: To investigate the post-activation potentiation (PAP) effects of different eccentric overload (EOL) exercise volumes on countermovement jump (CMJ) and standing long jump (LJ) performance.

Methods: Thirteen male university soccer players participated in a cross over design study following a familiarization period. Control (no PAP) CMJ and LJ performances were recorded, and three experimental protocols were performed in a randomized order: 1, 2 or 3 sets of 6 repetitions of flywheel EOL half-squats (inertia=0.029 kg·m^2). Performance of CMJ and LJ were measured at 3 and 6 min following all experimental conditions. The time course and magnitude of the PAP were compared between conditions.

Results: Meaningful positive PAP effects were reported for CMJ after 2 (Bayes factor [BF_{10}]=3.15, *moderate*) and 3 (BF_{10}=3.25, *moderate*) sets but not 1 set (BF_{10}=2.10, *anecdotal*). Meaningful positive PAP effects were reported for LJ after 2 (BF_{10}=3.05, *moderate*) and 3 (BF_{10}=3.44, *moderate*) sets but not 1 set (BF_{10}=0.53, *anecdotal*). Two and three set protocols resulted in meaningful positive PAP effects on both CMJ and LJ after 6 but not 3 min.

Conclusion: This study reported beneficial effects of multiple-set eccentric overload exercise over a single set. A minimum of two sets of flywheel EOL half-squats are required to induce PAP effects on CMJ and LJ performance of male university soccer players. Rest intervals of around 6 min (greater than 3 min) are required to maximize the PAP effects via multiple sets of EOL exercise. However, further research is needed to clarify the optimal EOL protocol configurations for PAP response.

Keywords: strength, training, flywheel, squat, Bayesian statistics

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Introduction

Acute enhancement of force and power production underpins successful execution of sporting tasks by athletes of varying levels.[1–3] Such enhancement of voluntary muscle contractions has previously been termed post-activation potentiation (PAP).[4] Several physiological mechanisms leading to temporary neuromuscular and biochemical adaptations in the musculoskeletal system are proposed to contribute to the PAP phenomenon.[4,5] The most accredited theory relates to an upsurge of Ca^{2+} sensitivity in the sarcoplasmic reticulum, increasing phosphorylation of myosin regulatory light chains, and enhancing twitch force and rate of force development.[4] Based upon this rationale, PAP protocols are implemented to enhance athletic performance prior to competition or during training.

Various methods have been used to induce PAP in athletes and untrained populations.[1–3] These protocols implemented either maximal isometric actions or dynamic heavy resistance exercise loads (*e.g.* > 85% 1RM) to induce an acute effect on performance.[6,7] However, a recent body of research has suggested using alternative conditioning activities that are biomechanically similar to the subsequent exercise in terms of the kinematic and kinetic variables associated with the movements, and the muscle actions involved.[8,9] Among other methodologies, eccentric overload (EOL) exercise has consistently proven to be effective for acutely improving horizontal and vertical jumping performance.[5,10,11] Such exercise utilizes the physiological advantages offered by a greater loading of the eccentric phase of the exercise (*e.g.* squat).[12] This overload facilitates greater motor unit recruitment and triggering of sarcoplasmic calcium release,[13] considered the main central and peripheral mechanisms underpinning PAP[10] Eccentric exercise has also been shown to selectively recruit type II muscle fibres,[12] which are more sensitive to the PAP phenomenon,[13,7] From a methodological perspective, EOL only requires a short familiarization process even for athletes without extensive experience of traditional weightlifting.[14] Such a short amount of time is a negligible cost in view of the possible performance benefits. Moreover, flywheel devices have the advantage of being easily transportable compared to traditional weightlifting devices, supporting their utilization in an applied context.

While EOL has been extensively studied as a training strategy, [1,12,13,15,16] the topic remains relatively unexplored as an approach to stimulate PAP effects. In particular, the modalities necessary to optimally elicit a PAP response, via manipulation of intensity (inertia) and volume (number of sets), affecting the fatigue-potentiation relationship and the consequent time-course of the PAP effects, are still unknown.[4,9] Conditioning exercise volume may have an important impact on both the onset and magnitude of PAP effects, which are crucial for practitioners attempting to optimize jump,[1,13] sprint,[5,9,15] and change of direction performance.[16,17] The effects of different volumes on PAP effects have been marginal and only investigated with regard to traditional PAP protocols.[7,8] High volumes of traditional resistance exercise methods may cause excessive fatigue, either requiring a longer time window for PAP or possibly nullifying it.[6,7] Nonetheless, greater peak power responses have been observed following multi-set protocols (*e.g.* 2 and 3 sets) in comparison to a single-set protocol, even if no differences were observed in jump height.[2] Eccentric overload protocols present the potential advantage of maximizing the neuromuscular response via optimized use of the eccentric phase,[12] possibly reducing the volume necessary to elicit a PAP stimulus within complex training methodologies. Specifically, the management of EOL volume may play a key role in altering PAP time windows and magnitudes,[2,4] with fatigue being reduced at a quicker rate than muscular PAP and potentiation becoming dominant in the second part of the recovery period (generally after

3 min).[1] Considering the lack of evidence regarding the impact of flywheel EOL volume on PAP,[9] this investigation may help practitioners optimize volume prescription for PAP or complex training methodologies aimed at acutely enhancing athletic performance.[14,17]

The aim of this study was to compare the effects of different volumes (1 set *vs* 2 sets *vs* 3 sets) of flywheel EOL squats used as a PAP protocol on countermovement jump (CMJ) and standing long jump (LJ) performance of soccer players. We hypothesized that multiple sets (2-3 sets) may generate a more delayed but greater PAP response than a single set protocol (1 set).

Methods

Participants

Thirteen university male soccer players were recruited for this study (mean ± SD; age 20 ±1 years, body mass 72.1 ± 7.8 kg, height 1.79 ± 0.06 m). Inclusion criteria were the absence of any injury or illness (Physical Activity Readiness Questionnaire), and regular participation in soccer training (minimum two sessions per week) and competition (once per week). All participants were informed of the potential risks and benefits of the procedures and signed an informed consent form. The Ethics Committee of the University of Suffolk (UK), approved this study. All procedures were conducted according to the Declaration of Helsinki for studies involving human participants.

Experimental Design

A randomized, crossover study design was used to investigate the acute effects of different volumes (1 set *vs* 2 sets *vs* 3 sets) of EOL exercise on jumping performances. Participants did three familiarization sessions to become acquainted with the EOL exercise procedures.[14,16] They attended the laboratory on 4 further sessions.[14] During the first session, baseline CMJ and LJ performances were assessed and used as control measures (no PAP stimulus) to compare the effects of the three experimental protocols. During each of the remaining occasions, participants completed a standardized warm up, one of the three PAP protocols in a randomized order, and CMJ and LJ reassessment after 3, and 6 min of passive recovery (see Figure 1 for the study layout). Similar experimental procedures have been used in previous studies exploring acute responses to EOL exercise.[1,2,16]

Figure 1, here please

Procedures

Body mass and height were recorded by stadiometer with inbuilt scales (Seca 286dp; Seca; Hamburg, Germany). A standardized warm-up included 10 min of cycling at a constant power (1 W·kg^{-1} body mass) on an ergometer (Sport Excalibur lode, Groningen, Netherlands). Dynamic mobilization exercises for a duration of 3 minutes, using the same procedure previously described by this research group,[1,16] consisted in of dynamic movements mimicking the EOL exercise (e.g., half squat) and dynamic hip, knee, and ankle movements. Participants were asked to maintain habitual exercise habits and to refrain from consuming depressive (*e.g.* alcohol) or ergogenic (*e.g.* coffee) substances 24 hours prior to the experimental sessions.[15] All sessions were performed between 10:00 AM and 14:00 PM, at least 48 hours after the last competition or training session to avoid the effects of accumulated fatigue on performance.[2,18]

Countermovement jump (CMJ)

Countermovement jump height was assessed using Optojump technology (Optojump Next, Microgate, Bolzano, Italy).[17] Maximal CMJs were performed with a self-selected depth and with hands on hips to prevent the influence of arm swing.[3] Validity and reliability of this test were previously reported.[19] An *excellent* test-retest reliability was observed in the present study: intraday ICC=0.93, and inter-day ICC=0.90; which are in agreement with previous evidence.[1]

Standing long jump (LJ)

A LJ test was used to measure the horizontal jumping ability.[20] Participants performed one maximal bilateral anterior jump with arm swing. Jump distance was measured from the starting line to the point at which the heel contacted the ground on landing.[21] The validity and reliability of this test was previously reported in the literature.[22] A *good* test-retest reliability was observed in the present study: intraday ICC=0.90, and interday ICC=0.91; which are in agreement with previous evidence.[16]

PAP protocols

The PAP protocols consisted of EOL half squat exercises using a flywheel ergometer (D11 Full, Desmotec, Biella, Italy). The protocols were configured as either 1, 2, or 3 sets of 6 repetitions[1], interspersed by 2 min of passive recovery. Each movement was qualitatively evaluated by an investigator, offering kinematic feedback to the athletes as well as strong standardized encouragements to maximally perform each repetition. The load used for the protocols consisted of a combination of one large disc (diameter = 0.285 m; mass = 1.9 kg; inertia = 0.02 $kg \cdot m^2$) and one medium disc (diameter = 0.240 m; mass = 1.1 kg; inertia = 0.008 $kg \cdot m^2$). The inertia of the ergometer (D11 Full) was estimated as 0.0011 $kg \cdot m^2$. The total inertia utilized in this study was 0.029 $kg \cdot m^2$.[1] The participants were instructed to perform the concentric phase at maximal velocity and to achieve approximately 90° of knee flexion during the eccentric phase. The EOL inertia and procedure reported in this study was previously utilized with flywheel ergometers to produce a PAP effect and its full description has been recently reported.[1]

Statistical analysis

All statistical analyses were conducted using JASP (Amsterdam, Netherlands) software version 0.9.2. Data were presented as mean ± SD. The test-retest reliability was assessed using an intraclass correlation coefficient (ICC) and interpreted as follows: *excellent* ≥ 0.9; $0.9 >$ *good* ≥ 0.8; $0.8 >$ *acceptable* ≥ 0.7; $0.7 >$ *questionable* ≥ 0.6; $0.6 >$ *poor* ≥ 0.5; *unacceptable* < 0.5.[23] A fully Bayesian statistical approach was utilized to provide probabilistic statements.[24] The sample size power was calculated (based on a previous study using the same experimental protocol)[1] by G-power and corrected for a Bayesian infarction factor, n=13.[25] Each analysis was conducted with a "noninformative" prior (Cauchy distribution, 0.707).[25] A Bayesian-repeated measures ANOVA was used to evaluate the effects of time (within; control, 3 min, and 6 min) and conditions (between; 1 set vs. 2 sets vs. 3 sets) on CMJ and LJ performance. If a meaningful Bayes factor (BF_{10}) was identified, a post-hoc was performed.[26] Evidence for the alternative hypothesis (H_1) was set as $BF_{10} > 3$ and evidence for null hypothesis was set as $BF_{10} < 1/3$. BF_{10} was reported to indicate the strength of the evidence for each analysis (within and between), and interpreted using the following evidence categories: $1 <$ *anecdotal* evidence for $H_1 < 3$; *moderate* ≥ 3; *strong* ≥ 10; *very strong* ≥ 30; *extreme* ≥ 100.[27] Markov Chain Monte Carlo with Gibbs sampling was used to make inferences (10000 samples). Estimates of median standardized effect size (δ) and 95% credible interval (CI) were calculated.[28] δ was interpreted by Cohen as *trivial* < 0.2; *small* ≥ 0.2; *moderate* ≥ 0.6; *large* ≥ 1.2; *very large* > 2.0.[29]

Results

Meaningful positive PAP (time; Table 1) effects were reported for CMJ after 2 (BF_{10} = 3.15, *moderate*) and 3 (BF_{10} = 3.25, *moderate*) sets but not 1 set (BF_{10} = 2.10, *anecdotal*). Meaningful positive PAP (time; Table 1) effects were reported for LJ after 2 (BF_{10} = 3.05, *moderate*) and 3 (BF_{10} = 3.44, *moderate*) sets but not 1 set (BF_{10} = 0.53, *anecdotal*). Two and three set protocols resulted in meaningful positive PAP effects (post-hoc; Table 2) on both CMJ and LJ after 6 ($3.05 \leq BF_{10} \leq 7.64$) but not 3 min ($0.60 \leq BF_{10} \leq 1.31$). Post-hoc analysis was not performed for 1 set since no meaningful time effect was observed. A non-meaningful time x condition interaction was observed for CMJ (BF_{10} = 0.03; evidence for H_0) and LJ (BF_{10} = 0.06, evidence for H_0). No overall meaningful differences between conditions (sets) were observed in CMJ (BF_{10}=0.08, evidence for H_0) or LJ (BF_{10}=0.09, evidence for H_0). Post-hoc analysis between conditions were not performed since no meaningful interaction effect was observed.

Table 1 and Table 2 here, please.

Discussion

The current study is the first to investigate the effects of PAP protocols using flywheel EOL squats with different volumes on CMJ and LJ performance. Three findings emerged: firstly, time (PAP) effects on CMJ and LJ were observed only following the multi-set protocols and not the single-set protocol; secondly, these PAP effects were evident only after 6 min and not after 3 min of recovery; finally, no differences between conditions (number of sets) were reported on the onset or magnitude of CMJ and LJ performance enhancement.

The findings of the current study are in line with the recent evidence reporting improved horizontal and vertical jump performances following PAP protocols implementing EOL exercises.[1,16] These potentiating effects may arise from mechanical advantages and neuromuscular mechanisms associated with the execution of EOL exercises as potentiating activities prior to an athletic task. Eccentric overload is achieved due to the increased inertial load of the flywheel mechanism, which demands higher mechanical force and power production during the exercise.[1,16] In addition, eccentric contractions commonly induce both neural and muscular adaptations which are defined as the common central and peripheral mechanisms underpinning the PAP phenomenon.[6,30] Peripheral adaptations allowing for increased muscle responses may be associated with the passive factors that underpin the cross-bridge mechanisms, possibly relating to the binding of calcium to certain areas of titin, thereby enhancing stiffness and force upon lengthening during eccentric actions.[30] Furthermore, EOL may preferentially activate high-threshold (type II) fibers.[12,13,30]

The second main finding of this study highlighted that greater than 3 min of rest (*e.g.* 6 min) were necessary to elicit a PAP response. A large amount of literature supports the findings that a rest period is necessary for eliciting a PAP response.[4,6] Specifically, it appears that 3-7 min of rest are required for performance enhancement of jumping ability with traditional methods,[8] although another meta-analysis reported that 5-7 minutes were necessary.[7] Whist no PAP effect was present at 3 min in the current study, the time-course of the PAP effects reported are partially consistent with previous EOL PAP investigations, which reported enhanced CMJ and LJ performance after 3 and 6 min of rest.[1,16] Previously, a study reported differences in squat peak force and impulse after 5 minutes of passive recovery, which supports the present findings.[1] Although some uncertainty remains regarding optimal rest periods,[7,8] these findings highlight the importance of a recovery period between the completion of the PAP stimulus and the beginning of subsequent exercise. Furthermore, the lack of a meaningful difference in time window between conditions is in itself a new result.

The present study hypothesized that differences between 1 set and multiple sets of EOL squats on PAP response would have occurred as a consequence of the balance between transient fatigue and potentiation, both present at the completion of the conditioning activity.[1,2,7] A higher exercise volume may have increased the neuromuscular response, but may also have generated greater transient fatigue. Conversely, a lower EOL volume may have minimized the magnitude and duration of fatigue but may have failed to enhance muscular activation and subsequent athletic performance.[6,7,30] The current study reported that both 2 and 3 sets enhanced performance, whereas 1 set of EOL squats did not. Therefore, the findings of the current study support the use of multi-set EOL exercise to stimulate PAP,[7] in agreement with previous recommendations using traditional resistance methods.[8]

In previous studies, volume has been considered as a key modulator for PAP.[4,9] A recent investigation by Bauer et al.[2] comparing different volumes of traditional back squats reported enhanced jumping performance consistently throughout all sets, but significant peak power increases after 2 and 3 sets in comparison to 1 set. No previous studies have utilized a flywheel device to investigate the impact of EOL volume on PAP response. It has been supposed that the use of a small volume (1 set) of flywheel exercise could generate PAP effects based on the characteristics of the EOL exercise, which increases the mechanical demands during the eccentric portion of a squat and could, therefore, generate a PAP response within the previously reported time windows.[30] Considering the present findings, which did not observe a meaningful PAP response using such a volume, it is possible that the effectiveness of the EOL protocol may have been determined by the participants' ability to maximally recruit muscle in the eccentric portion of the movement. This may significantly impact both fatigue accumulated and muscle activation.[30] Therefore, it could be possible that athletes with extensive experience in EOL training could report different results compared to the inexperienced participants used in the current research. Alternatively, other factors (*e.g.* coordination) have been previously reported to impact jump performance, which could explain the current findings.[1–3] Future studies could use other measures, which involve a lower movement coordination, such as concentric knee flexion and extension peak torque via isokinetic testing. These measures, which are correlated with sport specific tasks such as jumping and sprinting ability, may offer further clarification on this topic.[1]

This study suffers from a number of limitations worthy of discussion. Firstly, although all the soccer players participated in familiarization sessions before the study initiated,[14] possible inter-participant differences in reaction to the novel conditioning activity used in this study may have played a role in PAP responses.[30] Further familiarization may possibly allow for greater adaptations to the unique neural activation patterns experienced during EOL contractions. Additionally, this study evaluated baseline (control) test values in a separate session and so possible learning effects should be considered as a limitation. Further investigations should replicate the current protocol recruiting other cohorts with a training background and different fitness levels.[1,2,9] Further research is needed to clarify whether the combined effects of intensity and volume could generate a different PAP response.[16] Multiple sets of using lower intensity may induce less fatigue and be more effective for less trained cohorts than higher intensity dynamic exercise.[8] Alternatively, higher intensities (0.075 - 0.1 $kg \cdot m^2$) may acutely enhance power production[14] and subsequent performance within elite cohorts.[8,30,31] Although different intensities of EOL squats have previously resulted in no meaningful difference in jump potentiation,[16] they may differentially activate musculature of the lower limbs in individuals.[18] Recording the power output during EOL exercise may help to clarify this.

Conclusion

This study is the first to have reported the beneficial effects of multiple-set eccentric overload exercise over a single set in a lower body multi-joint movement to elicit PAP. Jumping ability was enhanced after 6 but not 3 min of recovery, which makes the balance between transient fatigue and potentiation relevant also for eccentric overload conditioning activities. Further research is necessary to confirm whether such findings can be generalized for different populations (*e.g.* elite), as well as whether PAP response differences exist using differing exercise prescriptions such as volume, intensity or a combination of both of these variables.

Practical Applications

The results support using 2-3 sets of eccentric overload exercise as a valid preload strategy to enhance vertical and horizontal jumping performance in male athletes during training sessions or before competitions. However, single set eccentric overload protocols should not be recommended. These performance enhancements can be maximized after 6 min of passive recovery, while 3 min of recovery may be not sufficient, due to transitory fatigue, to elicit a PAP response. Practitioners should consider the PAP time window reported in the current study following an eccentric overload protocol to enhance the sport-specific performance of their athletes.

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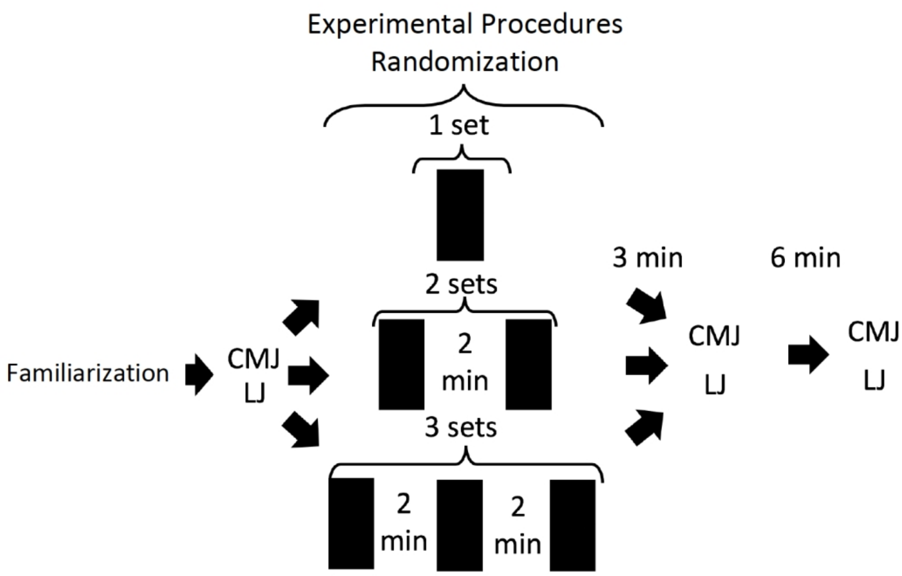
Figure 1. Flowchart of the study design and experimental procedures



CMJ = Countermovement jump; LJ = Standing long jump

298x225mm (144 x 144 DPI)

Table 1. Post-activation potentiation effects on CMJ height and LJ distance at 3 and 6 min after 1, 2, or 3 sets of flywheel half squats via Bayesian ANOVA.

Variable	Control Mean ± SDs	PAP 3 min Mean ± SDs	PAP 6 min Mean ± SDs	ANOVA BF_{10}	BF_{10} *Interpretation*
CMJ (cm)					
1 set	35.7 ± 5.7	37.6 ± 4.8	37.2 ± 5.7	2.10	*Anecdotal*
2 sets		37.5 ± 4.6	37.4 ± 5.3	3.15	*Moderate*
3 sets		37.1 ± 5.5	37.7 ± 6.1	3.25	*Moderate*
LJ (m)					
1 set	2.14 ± 0.15	2.19 ± 0.14	2.18 ± 0.14	0.53	*Anecdotal*
2 sets		2.19 ± 0.15	2.20 ± 0.14	3.05	*Moderate*
3 sets		2.18 ± 0.14	2.22 ± 0.18	3.44	*Moderate*

PAP = Post-activation potentiation; SD = standard deviation; CMJ = countermovement jump; LJ = long jump; BF_{10} = Bayes factor.

Table 2. Jump performance outcomes for the control and experimental conditions (2 and 3 sets). Post-hoc results for the conditions showing the magnitude of improvements in CMJ and LJ performance over time for different numbers of sets

Variable	**BF_{10} 3 min** ***Interpretation***	**BF_{10} 6 min** ***Interpretation***	**δ (95% CI) 3 min** ***Interpretation***	**δ (95% CI) 6 min** ***Interpretation***
CMJ (cm)				
2 sets	1.31 *Anecdotal*	3.05 *Moderate*	0.47 (-0.07, 1.05) *Small*	0.61 (0.01, 1.24) *Moderate*
3 sets	1.10 *Anecdotal*	7.64 *Moderate*	0.44 (-0.08, 1.00) *Small*	0.77 (0.19, 1.43) *Moderate*
LJ (m)				
2 sets	1.19 *Anecdotal*	4.36 *Moderate*	0.45 (-0.09, 1.03) *Small*	0.68 (0.09, 1.31) *Moderate*
3 sets	0.60 *Anecdotal*	6.67 *Moderate*	0.32 (-0.19, 0.85) *Small*	0.76 (0.15, 1.42) *Moderate*

PAP = post-activation potentiation; CMJ = countermovement jump; LJ = long jump; BF_{10} = Bayes factor; δ = effect size; CI = credible intervals.