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The Potentiating Effect of an Accentuated Eccentric Load on Countermovement Jump Performance

ABSTRACT

Post-activation potentiation (PAP) following a bout of high-intensity exercise of short duration is known to produce both a fatigued and a potentiated state. There has been much research in the effectiveness of various PAP protocols, yet the type of dynamic muscle action utilized has seldom been investigated. Therefore, the present study aimed to assess whether an accentuated eccentric load (AE) could enhance subsequent performance. Eleven males (21 ± 2 years, 179.1 ± 6.9 cm, 83.2 ± 10.1 kg) performed 3 countermovement jumps (CMJ) before and 6-minutes after a AE and a back squat (BSq) PAP protocol. The participant's maximum CMJ height (cm) was determined before and after both protocol. A two way RM ANOVA was conducted to evaluate the effect of PAP condition and time on vertical jumping performance. A significant condition × time interaction was found (P = 0.02). Post-hoc tests revealed that the AE PAP had a significant (P = 0.03) potentiating effect on CMJ jump height. Whereas, the BSq PAP revealed no significant differences (P = 0.32). In conclusion, this study has shown that jump performance can be enhanced by eccentric muscle action when compared to a traditional BSq PAP protocol. This may provide a more practical method for coaches to enhance short-term explosive movements in athletic populations.

Key words: Post Activation Potentiation; Ballistic exercise

INTRODUCTION

In most sports the rate of force development (RFD) may be a key determinant of sport performance (3). Enhancement of RFD via an optimal warm-up, immediately prior to a competitive event is paramount (17). Post-activation potentiation (PAP) is a mechanism by which muscle contractile ability is temporarily enhanced by a previous bout of maximal or sub-maximal muscle actions (6, 14, 18, 33). PAP is commonly considered as part of an effective warm-up with the aim of improving competitive performance.

Recently PAP has been the focus of an increasing degree of research (6, 14, 18, 33). A potentiation response has been produced via maximum voluntary contractions (MVCs) as well as dynamic resistance exercises such as squats or cleans (1). However, the contribution of different muscle actions (i.e., coupled eccentric-concentric muscle actions versus eccentric-only muscle actions) has seldom been investigated compared to other PAP influencing variables such as rest period and exercise intensity (15). Consequently, it is currently unclear if the potentiation response is caused or enhanced by the eccentric, the concentric, or the combined effect of both contractions.

While the exact physiological mechanisms producing the potentiation response are still debated, mechanisms such as the phosphorylation of myosin regulatory light chains (RLC) (16, 19) and enhanced neural excitability (improving motor unit recruitment) (20) are regularly discussed and thought to contribute. Considering mechanisms such as these it is possible that the unique process involved within an eccentric muscle action may have the ability to enhance the potentiation response.

It has been established that muscle performing eccentric actions is capable of generating 40-50% greater force than a muscle contracting concentrically (12, 21) (8). Further, it’s been evidenced that average electromyography was generally lower in eccentric actions at a range of force levels on an isokinetic dynamometer, demonstrating that eccentric muscle actions potentially produce greater amounts of force with lower levels of muscle activation (21). Furthermore, it has been shown that fast twitch muscle fibres are also selectively recruited during eccentric contractions (i.e., reverse size principle) (29), this is of particular interest to PAP as potentiation is reported to be primarily found in type II muscle fibres (31) and a precise balance of potentiation and fatigue (ref).

Some research has attempted to exploit the potential benefits of using enhanced eccentric loads to potentiate subsequent performance. A comparative study investigating the effect of a concentric only, eccentric only, isometric only and dynamic pre conditioning stimulus on bench press throw, showed no significant differences ($P > 0.05$) in peak power after the eccentric, concentric or dynamic contractions (11). Although, a significant improvement ($P < 0.05$) in peak power after the isometric condition was reported. However the isometric protocol was maximal in its nature (7s MVC), whilst the eccentric protocol was submaximal in its nature (3RM), therefore, pre-conditioning contraction dose may have an impact on the reported results making conclusions questionable. An evaluation of the effects of augmented eccentric loads (AELs) on vertical jump performance reported acute significant ($P < 0.05$) increases in jump height (32). Participants performed countermovement jumps (CMJs) holding a 10 kg weight plate in each hand and dropped the plates at the bottom of the countermovement before the initiation of the concentric jumping action. An explanation for this result may be that, the load used for the eccentric portion of the activity is greater than the concentric phase in order to overload the eccentric muscle action and further enhance the following concentric contraction (27). Although an AEL has been found to enhance acute performance, this adaptation is usually targeted towards training and chronic improvements. This is supported when analysing the work conducted by Hilfiker et al. (2007), where the effect of five modified 60-cm drop jumps (‘sticking’ a landing at 90^{o} knee flexion and no propulsive phase) on CMJ performance was investigated. A statistically significant improvement in relative CMJ power (W.kg) was reported, but no significant improvement in jump height after a 1-min rest period was evidenced. It can be speculated that a one-minute recovery period between the preconditioning stimulus and subsequent jump performance was inadequate. It may be possible that drop jumps with no propulsive phase and greater eccentric loading (augmented eccentric drops (AED)) may produce a greater potentiation effect due to the enhanced rate of muscle lengthening, concomitant increase in motor unit activation and potentially lower levels of fatigue (28).

Therefore, the primary aim of this study was to evaluate whether accentuated eccentric drops (AEs) had a potentiating effect on subsequent CMJ performance. This may provide great benefit to the practical PAP application due to a more desirable relationship between potentiation and fatigue. In addition, it was of particular interest to compare the potentiating effects of the AE PAP protocol with a well-established and recognised back squat (BSq) PAP protocol.

METHODS

Experimental Approach to the Problem

The aim of the present study was to investigate the effects of two differing PAP protocols on subsequent CMJ performance. A within-subject, crossover repeated measure study design was used to determine the potentiating effects of AEs and BSqs on subsequent CMJ performance. The testing order was randomized and counterbalanced. This study design cancels out any potential learning effects from the previous warm up intervention. The study was conducted over a 21-day period with 7 days separating each session. One familiarization and baseline testing session was carried out followed by two testing sessions. Participants were initially allocated a participation number and were subsequently assigned into two groups.

Subjects

Eleven male university students volunteered and completed a medical screening questionnaire and provided written informed consent (mean ± *SD* age 21 ± 2 years; body mass 83.1 ± 20.2 kg; height 179.1 ± 6.8 cm; BSq 1RM 124 ± 15kg. Body mass and standing height were measured using a balance beam scale (Seca 700, sca gmbh, Germany) and a stadiometer (SC126, Holtain, Wales) respectively. The study was approved by the University's Research Ethics Committee prior to the start of the investigation. For inclusion in the study, all participants were required to have at least six months of resistance training experience, proficient BSq technique (as assessed by a CSCS qualified coach) and no history of Achilles tendinopathy or lower limb trauma. Additionally, a BSq 1RM of more than 150% of body mass and appropriate landing mechanics (i.e. no knee valgus on landing) from a normalized box height was required and assessed by researchers.

Procedures

Each testing session began with a standardized five-minute dynamic mobility warm-up of the lower-body musculature associated with the back squat and jump squat, followed by three CMJs with 2 minutes of seated rest allowed at the end of the warm-up. During testing, all CMJs were performed on a mobile contact mat (Smartjump, Fusion Sport, Australia) where data was instantaneously collected via a hand-held PDA (iPAQ, Hewlett Packard, USA). Average intraclass correlation coefficients (ICCs) have previously been reported for measures CMJ (ICC = 0.83) heights obtained from the contact mat (22).

All CMJs were performed with both hands placed on the hip (to remove the influence of arm swing) followed by a rapid decent to a self-determined squat depth and an immediate aim to jump as high as possible. Jump height was calculated from the formula:

$$H = g \times ft^2/8$$

(where the jump height in cm; g is the gravity acceleration [9.81 $m \cdot s^2$]; ft is the flight time in ms) (4). Initial BSq 3RM was determined by the procedure outlined by (2). Both testing and performance of the BSq protocol was carried out after an additional four-minute rest period (post CMJ's). During the familiarization an additional 4-minute rest period was provided before AE familiarization. A 3-RM BSq load was chosen as it has often been shown to be the optimal load to achieve the greatest PAP effect (10, 14, 19). All BSqs in this study were performed to a parallel bottom position, which was determined consistently by the same researcher.

Six AEs were performed from a standardized box height of 60-cm which was utilized by a similar research study (15). During the AE, the participant began standing on top of the box with 0^o knee flexion, stepped off the box landing in a position of approximately 90^o knee flexion, with the instruction to stick the landing. Three drops were initiated by stepping off with the right leg leading and three were initiated with the left leg leading (25). To accentuate the eccentric action an additional 5% (mean ±*SD* 4 ± 0.5kg) of the participant's BM was added, which was provided by a weighted vest. This value was utilized because it has been shown to significantly increase ($P < 0.01$) ground reaction force and eccentric-RFD during drop jumps when compared to 0% and 10% of body mass (24).

During the testing sessions a 6-minute rest period was given following the preconditioning exercise for both groups. This rest period was selected following recommendations of the optimal recovery period for PAP being between 4 and 12-minutes depending on the athlete and their initial strength level (19).

Statistical Analyses

A two-way repeated measures ANOVA was conducted to evaluate the effect of PAP condition and time on vertical jumping performance. The independent variables were condition with two levels (BSqs and AEs) and time with two levels (pre and post). The only dependent variable measured was CMJ height. The time main effect and the condition × time interaction effect were analysed using tests of within subject effects (Mauchly's sphericity assumed). All analysis were conducted using SPSS 20.0. (SPSS, Inc., Chicago, IL) and the significant level was set at $P \leq 0.05$.

Cohen's *d* determined the magnitude of the treatment effect (i.e., change in height) using the effect size (ES) (30). Cohen's *d* was calculated using the following equation:

$$\text{Pre-Post Effect Size} = (\text{Post-test mean} - \text{Pre-test mean}) \div \text{Pre-test SD}$$

The magnitude of effect was classified as trivial if the ES was 0.25, small if the ES was between 0.25 and 0.50, moderate if the ES was between 0.50 and 1.0, and large if, the ES was greater than 1.0 (30).

RESULTS

A significant interaction effect was revealed ($P = 0.02$) (figure 1). Post hoc testing revealed that AEs had a statistically significant ($P = 0.03$) potentiating effect on CMJ height. Conversely, no significant difference ($P = 0.19$) in CMJ height occurred during the BSq PAP protocol. The effect size for the improvement in CMJ provided by the AEs was small, whereas there was a trivial effect size for the BSq PAP protocol (Table 2).

****Insert Figure 1 near here****

****Insert Table 2 near here****

DISCUSSION

The main findings in this study were that VJ height significantly increased following the AEs PAP protocol, with a non-significant negative change in VJ height following the BSq PAP protocol. These results suggest that AEs provided a potentiating stimulus while the BSq PAP protocol did not.

Although the present study has not directly measured the physiological changes contributing to the potentiation effect, it may be possible to speculate due to our understanding of both eccentric muscle action and PAP mechanisms. For example, one physiological change associated with PAP is the increased activation of fast twitch motor units (13). Interestingly, during an eccentric contraction it has been reported that fast twitch muscle fibres can be selectively recruited during eccentric actions which has been termed the reverse size principle (29). In addition, the force-velocity curves of concentric and eccentric muscle differ, concentric muscle actions exhibit decreases in force as velocity increases, whereas in an eccentric muscle action force is greatest when velocity is high (9). Therefore, the enhanced rate of muscle lengthening provided via AEs, may increase motor unit activation and synchronization, leading to the superior acute force-development (i.e., potentiation) of subsequent performance (28).

It has also been evidenced that following eccentric overloaded BSq there is elevated blood lactate values in comparison to traditional BSq (38). This supports the theory of the reverse size principle of eccentric muscle actions was and proposes that the results are evidence of greater eccentric-specific recruitment of fast glycolytic and/or fast oxidative glycolytic muscle fibres, indicating increased fast motor unit recruitment and associated lactate production during enhanced eccentric muscle actions (38). These studies (29, 38) provide evidence supporting the idea that the enhanced eccentric loading experienced during AEs may selectively recruit high threshold motor units because of the increased rate of muscle lengthening and increased muscle activation. This may be the primary mechanism responsible for the potentiating effect of AEs that subsequently enhanced CMJ performance to significantly increase jump height.

Skeletal muscle activity strongly depends on muscle temperature (7) and it has been shown that maximum force production and RFD decrease with a decrease in muscle temperature (26). Specifically, reporting that the decrease in muscle temperature was correlated to a decrease in sprint performance (r = 0.60, $P < 0.05$) in male soccer players ($n = 16$) (26). Interestingly, it has been found that high-velocity eccentric actions can increase intra-muscular temperature more than isometric or concentric muscle actions alone (34). Intra-muscular temperature enhances power by stimulating muscle spindle activity increasing the potential for force production (5). Therefore, the performance enhancing effects of AEs may also be in part explained by increased intra-muscular temperature.

It may be possible to somewhat explain the discrepancy of PAP interventions in the present study by examining the trade-off between potentiation and fatigue (23). Although, the BSq PAP protocol may have provoked a potentiating effect, it may have also provoked greater fatigue compared to AEs (17). The increased fatigue experienced is likely due to the eccentric-concentric muscle action used in the BSq exercise compared to the eccentric-only muscle action required to decelerate the body's momentum during the AEs, which may have increased the energy cost of the exercise (36). This may be an indication that the eccentric-concentric muscle action performed during the BSq PAP protocol had a greater energy cost than the eccentric-only contraction performed during AEs. This suggests that in the present study that the increased energy cost of eccentric-concentric contractions during the BSq may have contributed to the greater magnitude of potentiation evidenced in the AE protocol. Given that in the present study a 6-minute recovery period was utilized for both PAP protocols, may provide evidence suggesting that more fatigue is produced in the BSq exercise compared to AEs, and more importantly more time is needed to dissipate this fatigue. This could potentially make AEs advantageous for producing a potentiating effect in a limited amount of time. This highlights the importance of selecting the appropriate recovery period for the intensity of the exercise selected.

In conclusion, the BSq PAP protocol utilized in the present study supports the findings of other researchers (19, 23) that have found that for a high-intensity BSq protocol, an eight-12 minute recovery period may be required to take advantage of the potentiating effects of the exercise. In addition, although not directly analysed in this study, the athlete's initial strength appears to be associated with their ability to utilize the PAP phenomenon during this type of protocol (37). Conversely, it appears that a six-minute recovery period after AEs is adequate time to dissipate fatigue and produce a potentiating effect of subsequent performance. Furthermore, the mechanisms responsible for the positive PAP effect during AEs are likely due to the greater eccentric loading, which enhanced neural excitability and enabled selective recruitment of high threshold motor units (i.e., reverse size principle) (29). As well as increasing muscle temperature (34), and generating lower levels of fatigue (35) compared to the BSq PAP protocol.

PRACTICAL APPLICATIONS

When considering any PAP protocol used to potentiate acute performance, sport disciplines with a single action (e.g., long jump, high jump) would probably benefit the greatest because a series of contractions during repetitive team sports (e.g. basketball or football) will themselves have a potentiating effect. The logistical issues of integrating a PAP protocol into an athlete's warm up prior to a sporting event can be problematic because of the time restraints and the equipment available. In addition, a coach will have to allow a minimum of eight-12 minute of recovery following the preconditioning stimulus (19, 23), which may not appropriately fit into an athlete's warm-up preparation. However, AEs may provide a similar or greater PAP effect as a BSq PAP protocol and logistically would be easier to utilise in a real world setting. It may be possible to have a plyometric box on track side with a weighted vest to provide an appropriate preconditioning stimulus before a competition. In addition, the results of previous research (15) and the present study indicate that a PAP effect can be achieved in less time (i.e., between one-to-six minutes), which will allow adequate time to include this PAP protocol into an athlete's warm-up.

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FIGURES

Figure 1: Potentiating effects of two PAP protocols. Solid line = AE, Dashed line = BSq. * denotes sig diff (*P < 0.05)*