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Effect of Postactivation Potentiation After Medium vs. High Inertia Eccentric Overload Exercise on Standing Long Jump, Countermovement Jump, and Change of Direction Performance

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Abstract

Beato, M, De Keijzer, KL, Leskauskas, Z, Allen, WJ, Dello Iacono, A, and McErlain-Naylor, SA. Effect of postactivation potentiation after medium vs. high inertia eccentric overload exercise on standing long jump, countermovement jump, and change of direction performance. *J Strength Cond Res* XX(X): 000–000, 2019—This study aimed to evaluate the postactivation potentiation (PAP) effects of an eccentric overload (EOL) exercise on vertical and horizontal jumps and change of direction (COD) performance. Twelve healthy physically active male subjects were involved in a crossover study. The subjects performed 3 sets of 6 repetitions of EOL half squats for maximal power using a flywheel ergometer. Postactivation potentiation using an EOL exercise was compared between a medium (M-EOL) vs. high inertia (H-EOL) experimental condition. Long jump (LJ) was recorded at 30 seconds, 3, and 6 minutes after both EOL exercises and compared with baseline values (control). The same procedure was used to assess countermovement jump (CMJ) height and peak power and 5-m COD test (COD-5m). A fully Bayesian statistical approach to provide probabilistic statements was used in this study. Long jump performance reported improvements after M-EOL and H-EOL exercise (Bayes factor [BF_{10}] = 32.7, *strong*; BF_{10} = 9.2, *moderate*), respectively. Countermovement jump height (BF_{10} = 135.6, *extreme*; $BF_{10} > 200$, *extreme*), CMJ peak power ($BF_{10} > 200$, *extreme*; BF_{10} = 56.1, *very strong*), and COD-5m (BF_{10} = 55.7, *very strong*; BF_{10} = 16.4, *strong*) reported improvements after M-EOL and H-EOL exercise, respectively. Between analysis did not report meaningful differences in performance between M-EOL and H-EOL exercises. The present outcomes highlight that PAP using an EOL (M-EOL and H-EOL) improves LJ, CMJ height, CMJ peak power, and COD-5m in male athletes. The optimal time window for the PAP effect was found for both EOL conditions from 3 to 6 minutes. However, M-EOL and H-EOL produce similar PAP effect on LJ, CMJ, and COD-5m tasks.

Key Words: warm-up, power, flywheel, sprint, training

Introduction

Postactivation potentiation (PAP) is defined as an acute improvement in performance after a preload stimulus (15). Literature shows that neuromuscular, mechanical, biochemical, and physiological acute variations may explain the temporary improvements in muscular performance (6,31). Although the physiological mechanisms related to PAP are not well known, the most accredited theory reports that such performance improvements may be related to the phosphorylation of the myosin regulatory light chains during a muscle contraction, leading to a greater rate of cross-bridge attachment (13).

Postactivation potentiation following preload protocols has been used to acutely improve lower-limb power and sport-specific performance in competitions and training sessions (1). A PAP effect may be obtained using resistance exercises involving isometric, concentric, or eccentric contractions. A common way to obtain PAP is to perform a resistance exercise before a sport-specific task, e.g., a previous study used a parallel back squat (e.g., 1 × 5 repetition maximum) that showed an acute increase in countermovement jump (CMJ) height (29). It was reported that the PAP effect (after a traditional resistance exercise) began after around 3 minutes and persists for approximately 10 minutes. However, there has not been unanimous agreement regarding the starting time of this phenomenon (24). The core of studies analyzing PAP effects on sport performance has involved mainly traditional resistance exercises (16,17,31), while little research has been conducted using inertial exercise methodologies (3).

Isoinertial devices, also known as flywheel ergometers, can be used to perform an eccentric overload (EOL) protocol. These have been largely used to produce chronic adaptations (32). Nevertheless, only a few studies have analyzed the acute performance benefits offered by this protocol. The rationale underpinning EOL exercise is associated with the involved concentric and eccentric muscle contractions. During the concentric phase, the athlete rotationally accelerates the flywheel; this rotation results in a flywheel inertial torque that imparts high vertical resistance during the eccentric phase. As a result, the eccentric phase is more demanding than the concentric phase (higher power and force developed) during a squat exercise (23,27). Therefore, the main advantage of EOL during a squat exercise is related to an enchained mechanical load (during the eccentric phase) that is not possible using traditional weightlifting

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exercises (isotonic model). Contrastingly, in isotonic exercises, the concentric phase is more demanding than the eccentric phase (3,32). The advantages of eccentric resistance exercise on subsequent performance have been reported by previous authors (18,32), e.g., EOL protocol reported a positive PAP effect on jump and sprint performance in soccer players (14); moreover, improved lower-limb (e.g., jump action) performance was reported in swimmers (11). However, those studies did not clearly explain the PAP time window after EOL exercise or provide an exhaustive description of the acute improvements of vertical jump performance (magnitude of the effect). A recent article has analyzed the CMJ performance after an EOL exercise, reporting that jump height and lower-limb power increased meaningfully compared with the control condition (3). Moreover, a clear onset of the PAP phenomenon has been found at 3 minutes, while jump performance was nonmeaningful immediately after the end of the EOL bout (e.g., 20 seconds and 1 minute). The authors explained this finding considering the acute negative effect of fatigue accumulated after the resistance exercise, which may have affected the jump kinetics or kinematics (3). However, this is the first study analyzing this argument, and so, future evidence is needed.

Several factors may affect PAP response (magnitude) and time window (PAP onset) such as modality and intensity of the EOL exercise (6). A recent article has showed that light loads may be more beneficial than heavy loads to stimulate the PAP effect using traditional weightlifting (17). There is no evidence on this argument related to EOL exercise modalities (e.g., intensity) and acute sport-specific physical tasks. An EOL exercise using different flywheel inertias (i.e., intensities) may produce a different acute effect on performance. Moreover, a different EOL intensity may produce a different PAP optimal time window. Therefore, further studies on this argument are needed to inform the resistance training modalities used to stimulate acute responses in sporting populations.

Currently, no data are available regarding the PAP magnitude or time window after medium inertia (M-EOL) vs. high inertia (H-EOL) flywheels exercises. Such information may be paramount for athletes' strength training strategies and power optimization using flywheel devices. It is well known that horizontal and vertical jump performances represent lower-limb power and are prerequisites for many sporting actions (8,22). Moreover, change of direction (COD) tasks are a critical component for team sports because players need to perform many shuttle running activities during a match (2,9,35). Thus, the aims of this study were, first, to evaluate the time window effects of PAP after an EOL exercise (half squat) vs. baseline condition (control) on standing long jump (LJ), CMJ performance (jump height and peak power), and COD ability in male athletes and, second, to assess the acute effect of M-EOL and H-EOL exercise on the same physical tests.

Methods

Experimental Approach to the Problem

This study used a randomized, crossover design to evaluate the acute effects induced by EOL exercise (M-EOL vs. H-EOL) on sport-specific performance. Each subject attended the laboratory on 7 separate occasions. The first visit served to record baseline testing data such as LJ, CMJ, and COD and subsequently to familiarize subjects with the EOL exercise. Each subject had previous knowledge of testing procedures and EOL training. Within the remaining visits, the subjects performed 1 of 6 testing protocols in a randomized order after a standardized warm-up: LJ after M-EOL or H-EOL; CMJ after M-EOL or H-EOL; and COD after M-EOL or H-EOL. Each test was performed 30 seconds, 3, and 6 minutes after completion of the EOL exercise (M-EOL or H-EOL). The authors using this approach considering limited the confounding effect of repeated jumps as previously reported (1,3). These time windows were used to observe PAP optimization, as used with success in previous studies (1,3).

Subjects

Twelve healthy physically active male subjects were enrolled in this study (mean ± *SD*; age 21 ± 3 years [18–26 years old], mass 81 ± 13 kg, and height 1.82 ± 0.07 m). Inclusive criteria for participation were the absence of any injury or illness (Physical Activity Readiness Questionnaire) and regular participation in training (minimum 2 sessions per week) and competitions (athletes from different sports were enrolled including soccer, American football, and weightlifting). All subjects were informed about the potential risks and benefits of the current procedures and signed an informed consent form. The Ethics Committee of the School of Science, Technology, and Engineering, University of Suffolk (United Kingdom), approved this study. All procedures were conducted according to the Declaration of Helsinki for studies involving human subjects.

Procedures

Body mass and height were recorded by stadiometer (Seca 286dp; Seca, Hamburg, Germany). A standardized warm-up including 10 minutes of cycling at a constant power (1 W per kg of body mass) on an ergometer (Sport Excalibur lode, Groningen, the Netherlands) and dynamic mobilization was performed in both the control and experimental conditions (3). Mobilization was performed immediately after the cycling warm-up for a duration of 3 minutes and consisting of dynamic movements mimicking the EOL exercise (e.g., half squat) and dynamic hip, knee, and ankle movements.

Standing Long Jump. A LJ test was used in this study to test the anterior nonrebounding jumping ability (explosive strength capabilities of the leg musculature) (5). Players performed 1 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 (2). The validity and reliability of this test were previously reported in literature (21). A *good* test-retest reliability (intrasession) was found in this study: $\alpha = 0.88$.

Countermovement Jump. Countermovement jump was assessed using a force platform (Kistler, Winterthur, Switzerland; 900 × 600 mm; 1,000 Hz). Maximal effort CMJs were performed with a self-selected depth and with hands on hips to prevent the influence of arm swing (25). Countermovement jump height and peak vertical power were calculated in MATLAB (Version R2017b; The MathWorks Inc., Natick, MA, USA) using the impulse method (26,30). Jump height was defined as the peak height of the center of mass relative to standing (take-off height plus flight height). Power was calculated as the dot product of mass center velocity and ground reaction force. An *excellent* test-retest reliability (intrasession) was previously found in this laboratory for CMJ height and vertical power: $\alpha = 0.91$ and $\alpha = 0.92$ (3).

Change of Direction. Change of direction was tested through the 5-m shuttle run (COD-5m) consisting of 2 × 5-m sprints separated by a dominant leg unilateral 180° turn as typical in many sports (7). One pair of infrared timing gates (Microgate, Bolzano, Italy) was positioned at the start and end location of the COD task in a standardized manner. Tests started on the "Go" command from a standing position, with the front foot 0.2 m from the photocell beam (2). An *excellent* test-retest reliability (intra-session) was found in this study: α = 0.91.

Intervention. Eccentric overload was performed by a half squat exercise using a flywheel ergometer (D11 Full; Desmotec, Biella, Italy). The PAP protocol consisted of 3 sets of 6 repetitions each at maximal velocity, interspersed by 2 minutes of passive recovery (3). Each movement was evaluated qualitatively by an investigator, offering kinematic feedback to the athletes and strong standardized encouragements to maximally perform each repetition. The following combined load was used for each subject during M-EOL exercise: 1 large disc (diameter = 0.285 m; mass = 1.9 kg; inertia = 0.02 kg·m^2) and 1 medium disk (diameter = 0.240 m; mass = 1.1 kg; inertia = 0.008 kg·m^2). The following load was used for each subject during H-EOL exercise: 1 pro disc (diameter = 0.285 m; mass = 6.0 kg; inertia = 0.06 kg·m^2). The concentric and eccentric velocities are generally higher using M-EOL than using H-EOL (23,27), but were not quantified in this study. The inertia of the ergometer (D11 Full) was estimated as 0.0011 kg·m^{-2}. The subjects were instructed to perform the concentric phase with maximal velocity and to achieve approximately 90° of knee flexion during the eccentric phase. The EOL procedure reported in this study was previously used with flywheel ergometers to produce a PAP effect, and its full description has been recently published (3).

Statistical Analyses

Statistical analyses were performed by JASP (Amsterdam, the Netherlands) software version 0.9.1. Data were presented as mean ± *SD*. The test-retest reliability was assessed using a fixed-effect model, intraclass correlation coefficient (ICC, Cronbach-α) and interpreted as follows: α ≥ 0.9 = *excellent*; 0.9 > α ≥ 0.8 = *good*; 0.8 > α ≥ 0.7 = *acceptable*; 0.7 > α ≥ 0.6 = *questionable*; 0.6 > α ≥ 0.5 = *poor*; and α < 0.5 = *unacceptable* (10,33). A fully Bayesian statistical approach to provide probabilistic statements was used in this study; therefore, traditional inferential statistics (e.g., *p* level) were not reported (28). A Bayesian adaptive sample size approach was used. Each analysis was conducted with a "noninformative" prior (Cauchy, 0.707). A Bayesian repeated-measures analysis of variance (ANOVA) was used to evaluate the effects of conditions (between; M-EOL vs. H-EOL) and time (within; baseline, 30 seconds, 3 minutes, and 6 minutes) on LJ, CMJ, and COD-5m performance. If a meaningful Bayes factor (BF_{10}) was found, a Bayesian post hoc correction was applied (34). Estimates of median standardized effect size and 95% credible interval were calculated (between factor analysis) (20). 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 (between and within). The BF_{10} was interpreted using the following evidence categories: $1 < BF_{10} < 3$ = *anecdotal* evidence for H_1; $BF_{10} \geq 3$ = *moderate*; $BF_{10} \geq 10$ = *strong*; $BF_{10} \geq 30$ = *very strong*; and $BF_{10} \geq 100$ = *extreme* (19).

Results

No interaction (time × condition) was found for LJ (BF_{10} = 0.30, *anecdotal*), CMJ height (BF_{10} = 0.18, *anecdotal*), CMJ peak power (BF_{10} = 0.23, *anecdotal*), or COD-5m (BF_{10} = 0.27, *anecdotal*).

The repeated ANOVA reported within differences (time) using M-EOL exercise in LJ (BF_{10} = 32.7, *very strong*), CMJ height (BF_{10} = 135.6, *extreme*), CMJ peak power (BF_{10} > 200, *extreme*), and COD-5m (BF_{10} = 55.7, *very strong*). The repeated ANOVA reported within differences (time) using H-EOL exercise in LJ (BF_{10} = 9.2, *moderate*), CMJ height (BF_{10} > 200, *extreme*), CMJ peak power (BF_{10} = 56.1, *very strong*), and COD-5m (BF_{10} = 16.4, *strong*). A graphical representation of time effect on LJ and COD-5m was reported in Figure 1, while a representation of time effect on CMJ height and CMJ peak power was reported in Figure 2.

Bayesian post hoc comparing baseline value and time after M-EOL was reported for the following parameters: LJ at 30 seconds (BF_{10} = 0.3, *anecdotal*), 3 minutes (BF_{10} = 2.8, *anecdotal*), and 6 minutes (BF_{10} = 7.4, *moderate*); CMJ height at 30 seconds (BF_{10} = 0.4, *anecdotal*), 3 minutes (BF_{10} = 5.1, *moderate*), and 6 minutes (BF_{10} = 91.9, *very large*); CMJ peak power at 30 seconds (BF_{10} = 1.2, *anecdotal*), 3 minutes (BF_{10} = 3.8, *moderate*), and 6 minutes (BF_{10} = 5.7, *very large*); and COD-5m at 30 seconds (BF_{10} = 0.5, *anecdotal*), 3 minutes (BF_{10} = 107.4, *extreme*), and 6 minutes (BF_{10} = 12.7, *strong*).

Bayesian post hoc comparing baseline value and time after H-EOL was reported for the following parameters: LJ at 30 seconds (BF_{10} = 0.4, *anecdotal*), 3 minutes (BF_{10} = 4.2, *moderate*), and 6 minutes (BF_{10} = 7.2, *moderate*); CMJ height at 30 seconds (BF_{10} = 0.4, *anecdotal*), 3 minutes (BF_{10} = 104.8, *extreme*), and 6 minutes (BF_{10} = 33.2, *very large*); CMJ peak power at 30 seconds (BF_{10} = 0.4, *anecdotal*), 3 minutes (BF_{10} = 1.5, *anecdotal*), and 6 minutes (BF_{10} = 3.1, *moderate*); and COD-5m at 30 seconds (BF_{10} = 0.6, *anecdotal*), 3 minutes (BF_{10} = 1.9, *anecdotal*), and 6 minutes (BF_{10} = 12.0, *strong*).

The repeated ANOVA (between conditions) did not report differences in LJ (BF_{10} = 0.71, *anecdotal*), CMJ height (BF_{10} = 0.25, *anecdotal*), CMJ peak power (BF_{10} = 0.30, *anecdotal*), or COD-5m (BF_{10} = 0.47, *anecdotal*). Therefore, post hoc comparisons between M-EOL and H-EOL were not performed.

Discussion

To the best of the authors' knowledge, no research has previously evaluated the PAP time window effects after an EOL exercise vs. baseline conditions on LJ, CMJ, and COD-5m performance in sport athletes. Second, this is the first study that has compared the magnitude of the effect of M-EOL and H-EOL exercise on these physical tests. This study reported, first, a nonmeaningful performance variation at 30 seconds but a greater LJ, CMJ height, CMJ peak power, and COD-5s performance after 3 and 6 minutes after both M-EOL and H-EOL exercises (Figures 1 and 2). Second, between-condition differences in performance were not found between M-EOL and H-EOL in any physical test.

A preload activity such as EOL exercise may stimulate acute lower-limb performance improvements using the PAP principle. Postactivation potentiation is a temporary increase in muscular performance after a warm-up or resistance exercise (6). Previous studies reported lower-limb strength improvement after traditional resistance exercises (e.g., squat) (1). Several explanatory factors may be considered such as physiological and biochemical factors (3,31). The most common explanation associated with this transient performance improvement may be related to a decrease in passive stiffness and a greater actin-myosin interaction,

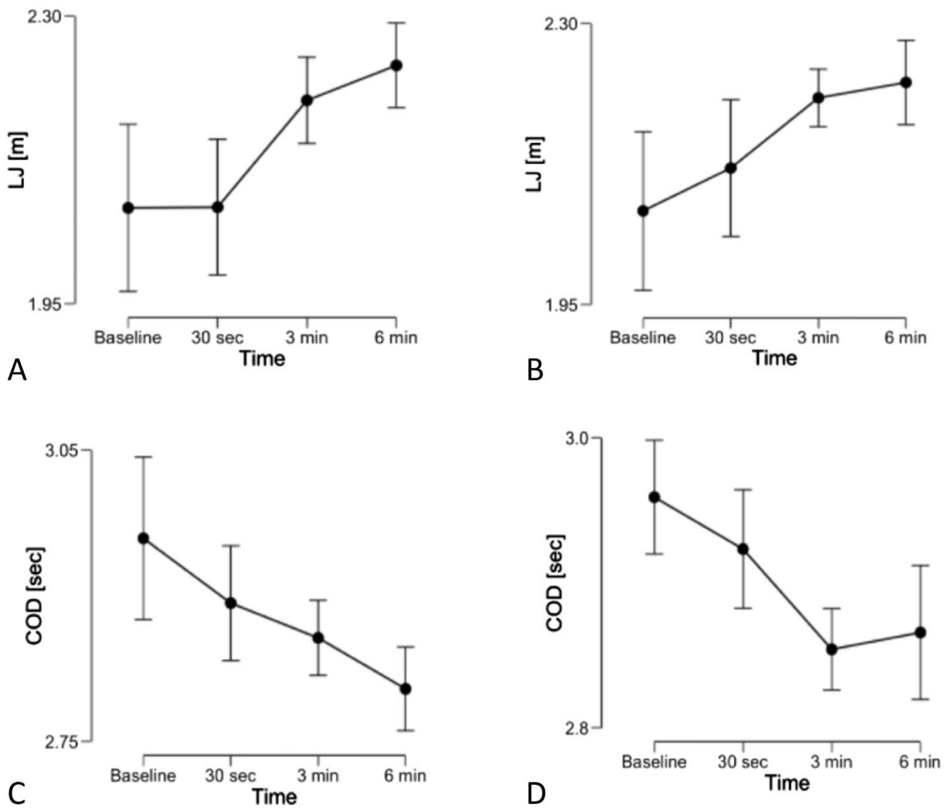

Figure 1. Postactivation potentiation time window after M-EOL and H-EOL exercise. Data reported as mean ± 95% credible interval (n = 12). A and C reported LJ and COD variations after M-EOL, while B and D reported LJ and COD variations after H-EOL. COD = change of direction; EOL = eccentric overload; LJ = long jump.

becoming increasingly sensitive to calcium (6). These physiological changes should increase temporarily the muscles' contractile capacities and therefore have a positive effect on force and power development. Such phenomena may explain the improvements in lower-limb performance reported in the current study (6). Previous evidence supports the positive effect of traditional resistance methods in stimulating acute muscle responses (1,16). Research on PAP response after an EOL exercise using a flywheel ergometer is missing (3).

The PAP time window observed in this study after an EOL exercise is supported by previous traditional resistance exercise studies reporting performance improvements in horizontal and vertical jumps after a recovery period (29). Several exercise factors may affect the PAP response such as inertia (intensity), number of repetitions (volume), recovery time, etc. It is well known that immediately after a preload exercise, fatigue response is dominant to PAP, but that fatigue dissipates at a faster rate. Postactivation potentiation therefore has the potential to improve muscle and sport-specific performance after a recovery period (31). In the current study, after both M-EOL and H-EOL exercises, physical performance (*e.g.* LJ, CMJ, and COD-5m) did not improve at 30 seconds compared with the baseline level, but increased meaningfully at 3 and 6 minutes. These results agree with a recent publication that did not find improvements in CMJ height and peak power immediately (20 seconds and 1 minute) after an EOL exercise but found meaningful performance increases from 3 to 10 minutes (3). Considering the results of the current study, it is clear that 3-minute recovery is sufficient to dissipate the fatigue accumulated during the EOL exercise and that this is irrespective of the inertia utilised (M-EOL vs. H-EOL). Previous research on traditional weightlifting, as in this study, found PAP onset to occur at 3 minutes and continue until around 10 minutes (3,6,31). These present findings can be considered innovative, since the time window after an EOL exercise on horizontal, vertical, and COD performance has not been previously described in the literature, and its knowledge can help practitioners to design effective training strategies.

The lower-limb performance improvements reported in this research after M-EOL and H-EOL (at 3 and 6 minutes) are supported by a previous study that found greater CMJ peak power, peak force, and impulse after an EOL exercise compared with control conditions (3). Such findings are also supported by other studies analyzing jumping performance improvements in a swimmer population after similar EOL exercise (11,12). However, such findings cannot be fully compared with the current results because of the test used, which is specific to swimming and differs to the horizontal and vertical jump assessments (LJ and CMJ) used in the current study (11,12). Furthermore, the COD performance improvements reported here (COD-5m) are supported by previous evidence that found improvements in sprinting and COD after an EOL exercise in football players (14). Those authors reported several *likely* and *possible* effects in favor of EOL exercise compared with control, but such data should be interpreted with caution. The authors used "magnitude-based inference" statistics, potentially increasing the likelihood of type 1 error (false-positive findings). The authors of the current study adopted a fully Bayesian approach to avoid this issue, as recently

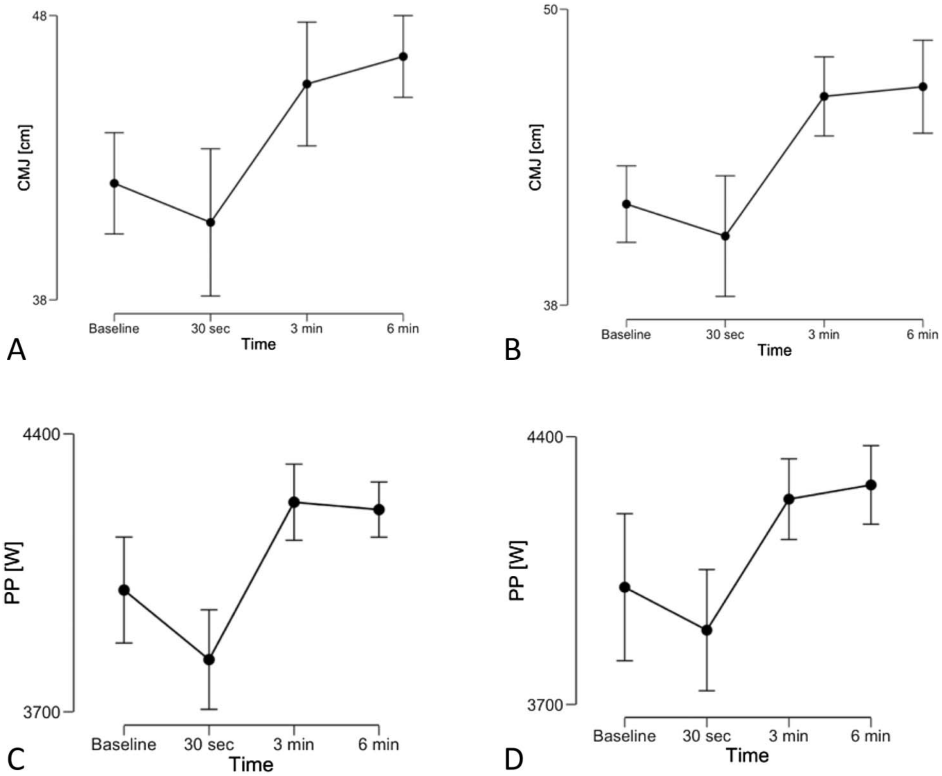

Figure 2. Postactivation potentiation time window after M-EOL and H-EOL exercise. Data reported as mean ± 95% credible interval (n = 12). A and C reported CMJ height and CMJ peak power variations after M-EOL, while B and D reported CMJ height and CMJ peak power variations after H-EOL. COD = change of direction; CMJ = countermovement jump; EOL = eccentric overload; LJ = long jump; PP = peak power.

recommended over "magnitude-based inference" (28). Limited evidence exists on the present topic, and additional research is needed to clarify PAP magnitude on jump and COD performance after EOL exercises. This is especially true given the potentially large variability in PAP response among different physical assessments (e.g., CMJ vs. sprinting), sport population (e.g., swimmers vs. strength athletes), subjects (amateurs vs. professional), and responders vs. nonresponders (1,3,6,17,31).

This study compared for the first time M-EOL vs. H-EOL without finding differences between the 2 conditions in any test (LJ, CMJ height, CMJ peak power, and COD-5m). No previous studies have compared such conditions; therefore, it is not possible to do an exhaustive comparison with the literature. The authors did not have a hypothesis a priori (e.g., H-EOL more effective than M-EOL, or vice versa) since previous studies were not available. However, it may be supposed that high-intensity exercises such as H-EOL may contribute to higher muscle stimulation than M-EOL. Therefore, a greater recruitment of higher order motor units, which may have produced a greater postsynaptic potential and H-wave, may be expected. These acute physiological changes may have produced a higher effect on PAP compared with M-EOL, but the present findings did not support this supposition. Further research could evaluate the potential for PAP magnitude (e.g., greater using H-EOL) beyond 6 minutes after preload exercise. These findings are supported by Bauer et al. (1) who reported an equivalent PAP effect after medium- and heavy-intensity traditional back squat exercise. In addition, a recent study showed that both heavy-loaded and power weightlifting exercises may induce a similar PAP response (17). The authors explain such results because of the dominant fatigue effect, which if too high (e.g., in H-EOL) may undermine the PAP benefits during the following recovery period (31). Considering that this study is the first to analyze M-EOL vs. H-EOL, the authors cannot claim a superiority of one EOL exercise intensity compared with the other. Therefore, practitioners may use both EOL protocols to acutely stimulate athletes before competitions and training sessions, but M-EOL may minimize acute fatigue, delayed-onset muscle soreness, and negative effects on training/performance later in the day. Further research is needed to better clarify the methodological EOL criteria for optimal PAP magnitude.

One limitation of this study is the recruitment of amateur male athletes only. Future studies may involve a different male population (e.g., elite athletes) or a female sample because nobody has previously studied this argument with such subjects. Therefore, PAP time window and magnitude after an EOL exercise may be different compared with that reported in this study. Second, future studies should investigate EOL exercise with different modalities such as type of exercise (e.g., half squat vs. quarter squat), number of sets (e.g., 3 vs. 1), repetitions (e.g., 6 vs. 10–12), and load (e.g., different inertias) that may affect the PAP time window and magnitude (4,6,31).

In conclusion, this study shows that both M-EOL and H-EOL exercises can increase the horizontal and vertical jump, as well as COD performance in a male athlete population. The PAP onset was found at 3 minutes, while performance is affected acutely by fatigue immediately after the exercise (30 seconds). This study has not found a difference in PAP time window or magnitude between M-EOL and H-EOL exercises; therefore, both modalities may be used with success to acutely stimulate subsequent performance (contrast training) (1).

Practical Applications

This study may have a great relevance for sport practitioners because of the innovative findings reported. M-EOL and H-EOL exercises may be proposed as a preload strategy to optimize strength and power development during training sessions or before competitions. The findings of this study underline that M-EOL and H-EOL exercises are both valid preload activities to stimulate a after sport-specific performance. Both methods have similar PAP time windows, where acute fatigue is dominant in the early part of the recovery period (e.g., 30 seconds) and PAP is dominant in the second part (e.g., 3 and 6 minutes). Practitioners should consider the PAP time window after an EOL exercise to optimize the sport-specific performance of their athletes.

References

1. Bauer P, Sansone P, Mitter B, Makivic B, Seitz LB, Tschan H. Acute effects of back squats on countermovement jump performance across multiple sets of a contrast training protocol in resistance-trained males. *J Strength Cond Res* 33: 995–1000, 2019.
2. Beato M, Bianchi M, Coratella G, Merlini M, Drust B. Effects of plyometric and directional training on speed and jump performance in elite youth soccer players. *J Strength Cond Res* 32: 289–296, 2018.
3. Beato M, Stiff A, Coratella G. Effects of postactivation potentiation after an eccentric overload bout on countermovement jump and lower-limb muscle strength. *J Strength Cond Res*, 2019. Epub ahead of print.
4. Bevan HR, Cunningham DJ, Tooley EP, Owen NJ, Cook CJ, Kilduff LP. Influence of postactivation potentiation on sprinting performance in professional rugby players. *J Strength Cond Res* 24: 701–705, 2010.
5. Bianchi M, Coratella G, Dello Iacono A, Beato M. Comparative effects of single vs. double weekly plyometric training sessions on jump, sprint and COD abilities of elite youth football players. *J Sports Med Phys Fitness*, 2018. Epub ahead of print.
6. Bishop D. Warm up I: Potential mechanisms and the effects of passive warm up on exercise performance. *Sports Med* 33: 439–454, 2003.
7. Chaouachi A, Manzi V, Chaalali A, Wong DP, Chamari K, Castagna C. Determinants analysis of change-of-direction ability in elite soccer players. *J Strength Cond Res* 26: 2667–2676, 2012.
8. Coratella G, Beato M, Milanese C, et al. Specific adaptations in performance and muscle architecture after weighted jump-squat vs. body mass squat jump training in recreational soccer players. *J Strength Cond Res* 32: 921–929, 2018.
9. Coratella G, Beato M, Schena F. The specificity of the Loughborough Intermittent Shuttle Test for recreational soccer players is independent of their intermittent running ability. *Res Sport Med* 24: 363–374, 2016.
10. Cronback L. Coefficient alpha and the internal structure of tests. *Psychometrika* 16: 297–334, 1951.
11. Cuenca-Fernández F, López-Contreras G, Arellano R. Effect on swimming start performance of two types of activation protocols: Lunge and YoYo squat. *J Strength Cond Res* 29: 647–655, 2015.
12. Cuenca-Fernández F, López-Contreras G, Mourão L, et al. Eccentric flywheel post-activation potentiation influences swimming start performance kinetics. *J Sports Sci* 00: 1–9, 2018.
13. Docherty D, Hodgson MJ. The application of postactivation potentiation to elite sport. *Int J Sports Physiol Perform* 2: 439–444, 2007.
14. de Hoyo M, de la Torre A, Pradas F, et al. Effects of eccentric overload bout on change of direction and performance in soccer players. *Int J Sports Med* 36: 308–314, 2014.
15. Dello Iacono A, Martone D, Padulo J. Acute effects of drop-jump protocols on explosive performances of elite handball players. *J Strength Cond Res* 30: 3122–3133, 2016.
16. Dello Iacono A, Padulo J, Seitz LD. Loaded hip thrust-based PAP protocol effects on acceleration and sprint performance of handball players. *J Sports Sci* 36: 1269–1276, 2018.
17. Dello Iacono A, Seitz LB. Hip thrust-based PAP effects on sprint performance of soccer players: Heavy-loaded versus optimum-power development protocols. *J Sports Sci* 36: 2375–2382, 2018.
18. Kohavi B, Beato M, Laver L, et al. Effectiveness of field-based resistance training protocols on hip muscle strength among young elite football players. *Clin J Sport Med*, 2018. Epub ahead of print.
19. Lee M, Wagenmakers E. Bayesian Cognitive Modeling. Cambridge, United Kingdom: Cambridge University Press, 2013. pp. 101–116.
20. Ly A, Verhagen J, Wagenmakers EJ. Harold Jeffreys's default Bayes factor hypothesis tests: Explanation, extension, and application in psychology. *J Math Psychol* 72: 19–32, 2016.
21. Markovic G, Dizdar D, Jukic I, Cardinale M. Reliability and factorial validity of squat and countermovement jump tests. *J Strength Cond Res* 18: 551–555, 2004.
22. Markovic G, Mikulic P. Neuro-musculoskeletal and performance adaptations to lower-extremity plyometric training. *Sports Med* 40: 859–895, 2010.
23. Martinez-Aranda LM, Fernandez-Gonzalo R. Effects of inertial setting on power, force, work, and eccentric overload during flywheel resistance exercise in women and men. *J Strength Cond Res* 31: 1653–1661, 2017.
24. McBride JM, Nimphius S, Erickson TM. The acute effects of heavy-load squats and loaded countermovement jumps on sprint performance. *J Strength Cond Res* 19: 893–897, 2005.
25. McErlain-Naylor S, King M, Pain MT. Determinants of countermovement jump performance: A kinetic and kinematic analysis. *J Sports Sci* 32: 1805–1812, 2014.
26. Moir GL. Three different methods of calculating vertical jump height from force platform data in men and women. *Meas Phys Educ Exerc Sci* 12: 207–218, 2008.
27. Sabido R, Hernández-Davó JL, Pereyra-Gerber GT. Influence of different inertial loads on basic training variables during the flywheel squat exercise. *Int J Sports Physiol Perform* 13: 482–489, 2018.
28. Sainani KL. The problem with "magnitude-based inference". *Med Sci Sport Exerc* 50: 2166–2176, 2018.
29. Scott SL, Docherty D. Acute effects of heavy preloading on vertical and horizontal jump performance. *J Strength Cond Res* 18: 201–205, 2004.
30. Street G, McMillan S, Board W, Rasmussen M, Heneghan JM. Sources of error in determining countermovement jump height with the impulse method. *J Appl Biomech* 17: 43–54, 2001.
31. Tillin NA, Bishop D. Factors modulating post-activation potentiation and its effect on performance of subsequent explosive activities. *Sports Med* 39: 147–166, 2009.
32. Vicens-Bordas J, Esteve E, Fort-Vanmeerhaeghe A, Bandholm T, Thorborg K. Is inertial flywheel resistance training superior to gravity-dependent resistance training in improving muscle strength? A systematic review with meta-analyses. *J Sci Med Sport* 21: 75–83, 2017.
33. Weir JP. Quantifying test-retest reliability using the intraclass correlation coefficient and the SEM. *J Strength Cond Res* 19: 231–240, 2005.
34. Westfall P, Wesley O, Utts J. A Bayesian perspective on the Bonferroni adjustment. *Biometrika* 84: 419–427, 1997.
35. Zamparo P, Zadro I, Lazzer S, Beato M, Sepulcri L. Energetics of shuttle runs: The effects of distance and change of direction. *Int J Sports Physiol Perform* 9: 1033–1039, 2014.