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# Effect of post-activation 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

This study aimed to evaluate the post-activation 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 cross-over study. The subjects performed 3 sets of 6 repetitions of EOL half-squats for maximal power using a flywheel ergometer. PAP 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 s, 3 min, and 6 min following both EOL exercises and compared with baseline values (control). The same procedure was utilised to assess countermovement jump (CMJ) height and peak power and 5-m change of direction test (COD-5m). A fully Bayesian statistical approach to provide probabilistic statements was used in this study. LJ performance reported improvements following M-EOL and H-EOL exercise (Bayes factor [$BF_{10}$]=32.7, *strong*; $BF_{10}$=9.2, *moderate*), respectively. CMJ 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 following 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 min. However, M-EOL and H-EOL produce similar PAP effect on LJ, CMJ and COD-5m tasks.

**Keywords:** warm-up; power; flywheel; sprint; training

## INTRODUCTION

Post-activation 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).

PAP 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.* 1x5 repetition maximum) that showed an acute increase in countermovement jump (CMJ) height (29). It was reported that the PAP effect (following a traditional resistance exercise) began after around 3 min and persists for approximately 10 min. However, there has not been unanimous agreement regarding the starting time of this phenomenon (24). The core of studies analysing PAP effects on sport performance have involved mainly traditional resistance exercises (16,17,31), while little research has been conducted using inertial exercise methodologies (3).

Iso-inertial devices, also known as flywheel ergometers, can be utilised to perform an eccentric overload (EOL) protocol. These have been largely utilised to produce chronic adaptations (32). Nevertheless, only a few studies have analysed 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 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 following EOL exercise, or provide an exhaustive description of the acute improvements of vertical jump performance (magnitude of the effect). A recent paper has analysed the CMJ performance following an EOL exercise, reporting that jump height and lower limb power increased meaningfully compared to the control condition (3). Moreover, a clear onset of the PAP phenomenon has been found at 3 min, while jump performance was non-meaningful immediately after the end of the EOL bout (*e.g.* 20 s and 1 min). Authors explained this finding considering the acute negative effect of fatigue accumulated after the resistance exercise, which may have affected the jump kinetics and/or kinematics (3). However, this is the first study analysing 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 paper has showed that light loads may be more beneficial than heavy loads to stimulate the PAP effect using traditional weight lifting (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 following 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 know that horizontal and vertical jump performances represent lower limb power and are pre-requisites for many sporting actions (8,22). Moreover, change of direction (COD) tasks are a critical component for team sports, since players need to perform many shuttle running activities during a match (2,9,35). Thus, the aims of the present study were: firstly to evaluate the time window effects of PAP following an EOL exercise (half squat) vs. baseline condition (control) on standing long jump (LJ), CMJ performance (jump height, peak power) and COD ability in male athletes; secondly, 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 utilised 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 one of six testing protocols in a randomized order following a standardized warm-up: LJ after M-EOL or H-EOL; CMJ after M-EOL or H-EOL; COD after M-EOL or H-EOL. Each test was performed 30 s, 3 min and 6 min after completion of the EOL exercise (M-EOL or H-EOL). 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 ± standard deviation (SD); age 21±3 years, mass 81±13 kg, 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, 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 (UK), 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 min of cycling at a constant power (1 W per kg of body mass) on an ergometer (Sport Excalibur lode, Groningen, Netherlands) and dynamic mobilization was performed in both the control and experimental conditions (3). Mobilisation was performed immediately after the cycling warm-up for a duration of 3 min and consisting of dynamic movements mimicking the EOL exercise (*e.g.* half squat), and dynamic hip, knee, and ankle movements.

*Standing long jump (LJ)*

A LJ test was utilised in this study to test the anterior non-rebounding jumping ability (explosive strength capabilities of the leg musculature) (5). Players 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 (2). The validity and reliability of this test were previously reported in literature (21). A *good* test-retest reliability (intra-session) was found in the present study: $\alpha = 0.88$.

*Countermovement jump (CMJ)*

CMJ was assessed using a force platform (Kistler, Winterthur, Switzerland; 900x600 mm; 1000 Hz). Maximal effort CMJs were performed with a self-selected depth and with hands on hips to prevent the influence of arm swing (25). CMJ height and peak vertical power were calculated in MATLAB (Version R2017b, The MathWorks Inc., Natick, MA) using the impulse method (26,30). Jump height was defined as the peak height of the centre of mass relative to standing (take-off height plus flight height). Power was calculated as the dot product of mass centre velocity and ground reaction force. An *excellent* test-retest reliability (intra-session) was previously found in this lab for CMJ height and vertical power: $\alpha$=0.91 and $\alpha$=0.92 (3).

*Change of direction (COD)*

COD was tested via the 5 m shuttle run (COD-5m) consisting of 2 x 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) were positioned at the start and end location of the COD task in a standardised 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 the present study: $\alpha$=0.91.

*Intervention*

EOL 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 min of passive recovery (3). Each movement was evaluated qualitatively by an investigator, offering kinematic feedback to the athletes as well as strong standardized encouragements to maximally perform each repetition. The following combined load was used for each subject during M-EOL exercise: one large disc (diameter=0.285 m; mass=1.9 kg; inertia=0.02 kg·m$^2$) and one 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: one pro disc (diameter=0.285 m; mass=6.0 kg; inertia=0.06 kg·m$^2$). The concentric and eccentric velocity 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 utilised with flywheel ergometers to produce a PAP effect, and its full description has been recently published (3).

**Statistical analysis**

Statistical analyses were performed by JASP (Amsterdam, Netherland) software version 0.9.1. Data were presented as mean±SD. The test–retest reliability was assessed using an unstandardized, fixed-effect model, intraclass correlation coefficient (ICC, Cronbach-$\alpha$) and interpreted as follows: $\alpha \geq 0.9$=*excellent*; $0.9 > \alpha \geq 0.8$=*good*; $0.8 > \alpha \geq 0.7$=*acceptable*; $0.7 > \alpha \geq 0.6$=*questionable*; $0.6 > \alpha \geq 0.5$=*poor*; $\alpha < 0.5$=*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 (a more conservative approach). A Bayesian repeated measure ANOVA was used to evaluate the effects of conditions (between; M-EOL vs. H-EOL) and time (within; baseline, 30 s, 3 min, 6 min) on LJ, CMJ, and COD-5m performance. If a meaningful Bayes factor ($BF_{10}$) was found, a Bayesian post-hoc (Bonferroni) correction was applied (34). Estimates of median standardized effect size and 95% credible interval (CI) 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*; $BF_{10} \geq 100$=*extreme* (19).

## RESULTS

No interaction (time x 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.

Please, Figure 1 and 2 here.

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

Bayesian post-hoc comparing baseline value and time following H-EOL was reported for the following parameters: LJ at 30 s ($BF_{10}$=0.4, *anecdotal*), 3 min ($BF_{10}$=4.2, *moderate*), and 6 min ($BF_{10}$=7.2, *moderate*); CMJ height at 30 s ($BF_{10}$=0.4, *anecdotal*), 3 min ($BF_{10}$=104.8, *extreme*), and 6 min ($BF_{10}$=33.2, *very large*); CMJ peak power at 30 s ($BF_{10}$=0.4, *anecdotal*), 3 min ($BF_{10}$=1.5, *anecdotal*), and 6 min ($BF_{10}$=3.1, *moderate*); COD-5m at 30 s ($BF_{10}$=0.6, *anecdotal*), 3 min ($BF_{10}$=1.9, *anecdotal*), and 6 min ($BF_{10}$=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 following an EOL exercise vs. baseline conditions on LJ, CMJ, COD-5m performance in sport athletes. Secondly, 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, firstly, a non-meaningful performance variation at 30 s but a greater LJ, CMJ height, CMJ peak power, and COD-5s performance after 3 min and 6 min following both M-EOL and H-EOL exercises (Figures 1 and 2). Secondly, between conditions differences in performance were not found between M-EOL and H-EOL in any physical test.

A preload activity like EOL exercise may stimulate acute lower limb performance improvements using the PAP principle. PAP is a temporary increase in muscular performance following a warm-up or resistance exercise (6). Previous studies reported lower limb strength improvement following 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, 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 following 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 following a preload exercise, fatigue response is dominant to

PAP but that fatigue dissipates at a faster rate. PAP therefore has the potential to improve muscle and sport-specific performance following a recovery period (31). In the current study, following both M-EOL and H-EOL exercises, physical performance (*e.g*. LJ, CMJ, and COD-5m) did not improve at 30 s compared to the baseline level, but increased meaningfully at 3 min and 6 min. These results agree with a recent publication that did not find improvements in CMJ height and peak power immediately (20 s and 1 min) after an EOL exercise but found meaningful performance increases from 3 min to 10 min (3). Considering the results of the current study, it is clear that 3 min 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 the present study, found PAP onset to occur at 3 min and continue until around 10 min (3,6,31). These present findings can be considered innovative, since the time window following 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 min and 6 min) are supported by a previous study that found greater CMJ peak power, peak force and impulse following an EOL exercise compared to control conditions (3). Such findings are also supported by other studies analysing jumping performance improvements in a swimmer population following similar EOL exercise (11,12). However, such findings cannot be fully compared to 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 following an EOL exercise in football players (14). Those authors reported several *likely* and *possible* effects in favour of EOL exercise compared to 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). Authors of the current study adopted a fully Bayesian approach to avoid this issue, as recently 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 following 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. non-responders (1,3,6,17,31).

This study compared for the first time M-EOL vs. H-EOL without finding differences between the two 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. 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 like H-EOL may contribute to a higher muscle stimulation than M-EOL. Therefore, a greater recruitment of higher order motor units, which may have produced a greater post-synaptic potential and H-wave may be expected. These acute physiological changes may have produced a higher effect on PAP compared to 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 min post pre-load exercise. These findings are supported by Bauer et al.(1) who reported an equivalent PAP effect following medium and heavy intensity traditional back squat exercise. Additionally, a recent study showed that both heavy-loaded and power weightlifting exercises may induce a similar PAP response (17). 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 analyse M-EOL vs. H-EOL, authors cannot claim a superiority of one EOL exercise intensity compared to the other. Therefore, practitioners may use both EOL protocols to acutely stimulate athletes before competitions and training sessions, but M-EOL may minimise 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 the present 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 since nobody has previously studied this argument with such subjects. Therefore, PAP time window and magnitude following an EOL exercise may be different compared to that reported in this study. Secondly, 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 min, while performance is affected acutely by fatigue immediately after the exercise (30 s). 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 APPLICATION**

The present 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 optimise 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 following 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 s) and PAP is dominant in the second part (*e.g.* 3 min and 6 min). Practitioners should consider the PAP time window after an EOL exercise to optimise the sport-specific performance of their athletes.

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Figure 1. PAP time window following M-EOL and H-EOL exercise. Data reported as mean ± 95% credible interval (n=12). A and C reported LJ and COD variations following M-EOL, while B and D reported LJ and COD variations following H-EOL.

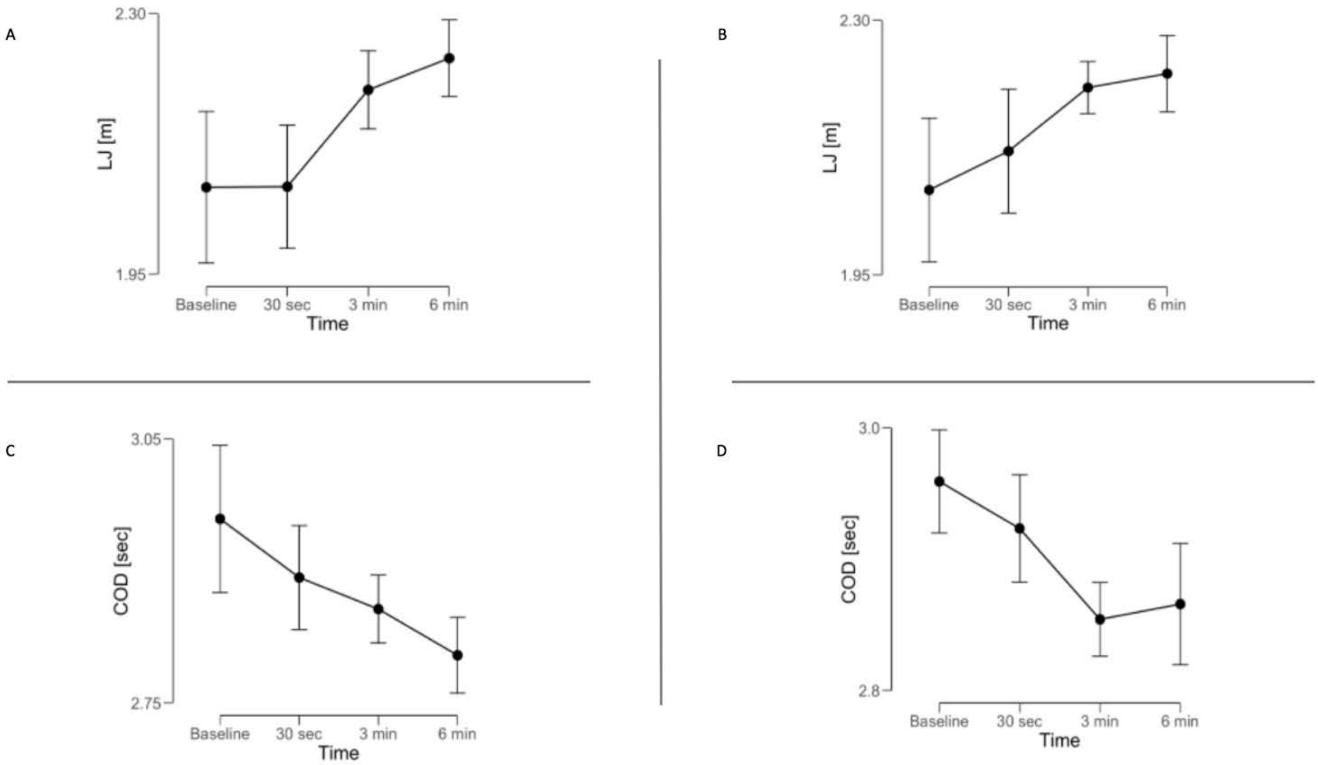

Figure 2. PAP time window following M-EOL and H-EOL exercise. Data reported as mean ± 95% credible interval (n=12). A and C reported CMJ height and CMJ peak power variations following M-EOL, while B and D reported LJ and COD variations following H-EOL.