**Acute effect of eccentric overload exercises on change of direction performance and lower-limb muscle contractile function**

**ABSTRACT**

This study aimed to evaluate the post-activation potentiation (PAP) effects following eccentric overload (EOL) exercises on changes of direction (COD) performance and muscle contractile function. Thirty-one male soccer players (age 21 ± 4 years; body mass 77.0 ± 5.2 kg) were involved in a cross-sectional study. Dominant-leg (COD-5mD) and non-dominant-leg (COD-5mND) shuttle tests were performed 4 min following the EOL exercises. Muscle contractile function was assessed by tensiomyography (TMG) such as muscle contraction time (Tc), time delay (Td) and displacement of the muscle belly (Dm) of vastus lateralis (VL), vastus medialis (VM), and rectus femoris (RF). EOL exercises were: a) cross-cutting step with inertial conical pulley (INC = 11 subjects), b) flywheel leg extension (EXT = 10 subjects), and flywheel yo-yo squat exercise (SQU = 10 subjects). Differences baseline-post were found on COD-5mD (p < 0.001) and on COD-5mND (p < 0.001) but not between groups (p > 0.05) following EOL exercises. Differences from baseline were found in VL Td (p < 0.001), VM Td (p = 0.003), RF Tc (p < 0.001), and RF Td (p < 0.001) with no significant differences between the EOL exercises. This study reported a significant positive PAP response on COD-5mD and COD-5mND after 4 min of recovery after EOL exercises (INC, EXT and SQU) in soccer players. For the first time, it has been reported that EOL exercises acutely affect TMG variables (*e.g.* Tc and Td) in lower limbs. Such results related to changes in muscular contractile functions may contribute to explain the physiological mechanisms (*e.g.* neuromuscular factors) associated with PAP effect.

**Keywords:** warm-up; power; flywheel; post-activation potentiation; training.

**INTRODUCTION**

Post-activation potentiation (PAP) is a physiological phenomenon related to acute neuromuscular and performance improvements (15,16). The most recognized mechanism of PAP is the greater sensitivity to calcium (Ca2+) because of the myosin regulatory light chain (RLC) phosphorylation (22,32), which increases the rate and level of force generated by the myofilaments because of the increase in the number of cross-bridges formed (8,30). Previous researchers have reported that PAP can be stimulated using a pre-load exercise (3,5,30). Indeed, several traditional weightlifting exercises have been used for such purposes, *e.g.* hip-thrust and back squat (3,18). Generally, a positive PAP response (after a pre-load activity) is reported following a short recovery period (around 3 minutes) and such beneficial effects may persist 10-12 min after the activity (2,3,30). Previous studies have reported sport-specific improvements in sprinting and jumping activities (3). Therefore, PAP may be used to increase the performance of a sport-specific task by a pre-load strategy, which is its main application in sport (18).

Flywheel ergometers are innovative strength devices (11,31) and one of the most unique characteristics of such ergometers is related to the high eccentric demand required of the athletes during exercises (28,33). For this reason, such exercise methods are defined as eccentric overload (EOL) (6,11). EOL offers the opportunity to generate a peak eccentric muscular force greater than the maximal force produced during the concentric contraction (23,31). This is very difficult to achieve during traditional weightlifting exercises (*e.g.* squat) (34). Flywheel devices have been used with positive results to stimulate PAP during sprinting and jumping activities (6,15). Moreover, following an EOL exercise some acute positive changes were reported in quadriceps and hamstring concentric peak torque (60°.s-1), as well as in hamstring eccentric peak torque (60°.s-1) during isokinetic tests (6). Despite such practical advantages and strong physiological rationale, the current knowledge on PAP response following EOL exercises is limited (6,10). This is particularly important considering the acute effects on change of direction (COD) tasks (5,15).

The critical importance of COD in multidirectional sports has been frequently reported (4,24,37). COD ability is defined as the capacity to decelerate quickly and accelerate in a new direction (36). COD performance, especially the deceleration phase, turning, and acceleration is characterized by high eccentric and concentric force production (38,39). Therefore, considering the specificity of COD, a PAP protocol induced by an EOL exercise may be beneficial in positively influencing performance (15). Moreover, the acute PAP effect may also be related to the EOL exercise used. In a recent study it was reported that PAP effect on a movement is associated with the vector direction of the pre-exercise performed relative to the athlete (17). For instance, a specific horizontal pre-load exercise (*e.g.* cross cutting step) may be more specific and, therefore, may offer a higher increment in performance in an horizontal test (*e.g.* COD) compared to a vertical loading pre-load exercise (*e.g.* squat) (5,17). This is an interesting hypothesis that has yet to be investigated.

Muscle contractile function can be evaluated *in* *vivo* by a non-invasive intramuscular pressure detecting method known as tensiomyography (TMG) (25,26). TMG has been used to assess sports performance and muscle contraction properties (21). Previous studies reported that TMG permits the evaluation of fluctuations in passive muscle stiffness, which is related to fatigue and to a decrement in muscle tension after exercises (40). TMG has reported a *good* to *excellent* test-retest reliability for contraction time (Tc) and maximal radial displacement of the muscle belly (Dm) (25); such information is critical for the use of TMG in sport. Piqueras-Sanchiz et al. recently observed some acute variations in contractile functions following an EOL exercise (25). Therefore, TMG may be useful to evaluate specific muscle acute changes (*e.g.* muscle stiffness assessed by Dm and muscle contraction velocity at 10% Dm [V10]) following an EOL exercise (21). For instance, an increment in stiffness (decrement in Dm) in the musculotendinous unit would induce a higher force-generation (19). Likewise, an increment in muscle contraction velocity is associated with positive muscle performance enhancements (25). As previously reported, EOL can be used to stimulate a PAP response (which is associated with phosphorylation of myosin regulatory light chains and augmented H-reflex) (30), therefore TMG may help to explain the acute performance improvements found in sport tasks (*e.g.* COD). Further knowledge on acute effects of EOL exercise on muscle contractile functions and on COD performance is needed for practitioners to optimize PAP strategies using flywheel devices.

Although EOL is a valid method to stimulate a PAP response in sport specific tasks, information related to COD and TMG are limited following such a type of protocol. Therefore, the aims of this study were, firstly, to evaluate the acute effect of three EOL protocols on a sport-specific short shuttle run involving a COD of 180º; and secondly, to compare the PAP effects on TMG parameters in lower limb muscles. Such knowledge may play a critical role for strength and conditioning practitioners.

**METHODS**

**Experimental approach to the problem**

The acute effects of EOL on COD performance and muscle contractile function were investigated in the present cross-sectional study (Figure 1). Each subject attended the laboratory on four separate occasions. In the first two sessions, subjects performed the baseline tests (COD and TMG). After that subjects were randomly assigned (balanced per group) to one of the following conditions (EOL exercises): a) cross cutting step using an inertial resistance conical pulley (INC = 11 subjects); b) flywheel leg extension (EXT = 10 subjects); or c) flywheel yo-yo squat exercise (SQU = 10 subjects). Following 4 min of passive recovery, each subject performed, randomly, COD and TMG (in two separate sessions). This specific time window was used in order to minimize transient fatigue and was based on previous studies (3,6). Specifically, the onset of a PAP time window has been recently identified at 3 min after a flywheel squat exercise (6). A standardized warm-up was conducted each session, including 10 min of standardized running (speed = 9 km.h-1) and dynamic mobilization (static stretching was not permitted). Dynamic mobilization was performed immediately after the running warm-up for a duration of 3 min and consisted of dynamic movements such as squats and hip, knee, and ankle movements (each group performed the same warm-up protocol) (5).

**Please, Figure 1 here**

**Subjects**

Thirty-one male amateur soccer players were enrolled in this study (mean ± SD: age 21 ± 4 years; body mass 77.0 ± 5.2 kg; height 1.82 ± 0.04 m). INC group had the following characteristics: age 21 ± 3 years, body mass 76.0 ± 5.5 kg, height 1.83 ± 0.03 m ; EXT group: 21 ± 5 years, 76.0 ± 5.1 kg, height 1.81 ± 0.04 m; SQU group: 21 ± 4 years, 78.0 ± 5.2 kg, height 1.83 ± 0.04 m. Body mass and height were recorded by Stadiometer (Seca 286dp, Hamberg, Germany). Inclusive criteria to participation were the absence of any injury or illness (Physical Activity Readiness Questionnaire). Regular participation in training activities (a minimum of 3 training sessions per week) as used in previous research (6). Subjects were previously familiarized with EOL exercises and test procedures as components of their soccer training and testing routine. All subjects were informed about the potential risks and benefits of the current procedures and gave informed consent. The Ethics Committee of **“information removed for review process”** approved this study. All procedures were conducted according to the Declaration of Helsinki for studies involving human subjects.

*Change of direction ability (COD-5m)*

COD ability was tested via the 5 m shuttle run consisting of 2 x 5 m sprints separated by a dominant leg (COD-5mD) or non-dominant leg (COD-5mND) 180° turn as typical in many sports (9). The rationale of the use of this COD test to evaluate acute PAP responses has been recently reported (5). One pair of infrared timing gates (Microgate, Bolzano, Italy) was positioned at the common start and end location of the COD task. Tests started on the “Go” command from a standing position, with the front foot 0.2 m from the photocell beam (4). An *excellent* test-retest reliability was found in the present study: ICC= 0.93.

*Tensiomyography (TMG)*

The TMG procedure used in the current study followed that reported by Loturco et al. (20). The measurements on the quadriceps were performed with the athletes in a supine position. The procedure for electrode placement between consecutive measurements, as well as the description of electric stimulation was previously reported (25). Maximum radial displacement of muscle (Dm), contraction time (Tc), and time delay (Td) were recorded for the vastus medialis (VM), rectus femoris (RF) and vastus lateralis (VL) of the dominant leg using one TMG device (TMG Measurement System, TMG-BMC Ltd., Ljubljana, Slovenia). Dm corresponds to the radial movement of the muscular belly expressed in millimeters and is related to the rigidity of the muscular belly. The Tc is obtained by determining the time interval from 10% to 90% of Dm, whereas Td represents the time (in ms) from onset to 10% of Dm (25). Mean velocities of muscle contraction (mm.s-1) from the onset of electrical stimulation until 10% (V10) and 90% (V90) of Dm were recorded. TMG has reported an *excellent* test-retest reliability for Tc and Dm such as 0.97 (95% Confident Interval [CI]: 0.92,0.99) and 0.96 (CI 0.89, 0.98), respectively (12,25). The reliability in TMG parameters in the current study (ICC = 0.91 to 0.96, *excellent*) is in line with previous research.

*Inertial-conic cross cutting step (INC)*

A cross cutting step (Figure 2a) using an inertial resistance produced by a conical pulley was used in this study (11). Rotational Inertia was produced by Eccotek Training Force® (Byomedic System SCP, Barcelona, Spain) consisting of a metallic disk (diameter: 0.42 m) with 18 weights (0.421 kg and 0.057 m of diameter each). The total moment of inertia was 0.194 kg.m2 based on a previous pilot study. The subjects executed 4 sets of 6 repetitions with each leg; the rationale for using a combination of multi-sets (29) and repetitions for PAP have been previously reported (5,6). A standard recovery time of 1 min between sets and 2 min between legs was used. The rationale for 2 min of recovery between sets was based on the following article (6). The above rationales for inertial load, sets, repetitions, and recovery time were used for each exercise condition (EXT and SQU). A qualified strength and conditioning coach gave feedback during the cross-cutting step exercise as well as during flywheel leg extension and squat exercise.

*Flywheel leg extension (EXT)*

Flywheel leg extension (Figure 2b) was performed with Eccophysic Training Force® machine (Byomedic System SCP, Barcelona, ​​Spain) in this study. The moment of inertia used during the exercise was 0.072 kg.m2. This value was which was based (and adjusted considered the unilaterality of the exercise) on previous studies using a inertia between 0.06 to 0.1 kg.m2, which reported positive acute and chronic responses following EOL exercises (5,25). The subjects sat on the machine with a hip and knee angle of 90°. The leg extension movement was performed unilaterally. The concentric power was calculated during the knee extension phase, while eccentric power was calculated during the knee flexion phase. The first two repetitions were performed sub-maximally to acquire momentum, while the 6 following repetitions were maximal. The subjects executed 4 sets for each limb. The recovery time between each unilateral set was 1 min with 2 min between exercise using the same leg (5,6).

*Squat exercise (SQU)*

The unilateral squat exercise (Figure 2c) was performed using an Eccopower Training Force® cylinder (Byomedic System SCP, Barcelona, Spain). The moment of inertia used to perform the exercise was 0.072 kg.m2 (which was adjusted based on the unilaterality of the exercise). The exercise was performed with one foot on the flywheel platform and the other positioned posteriorly to maintain balance during execution. The subjects were instructed to perform the concentric phase with maximal velocity and to control the eccentric phase until the knees where flexed to approximately 90° (6). Each subject performed 4 sets with each leg, with a recovery period of 1 min between each set. The first two repetitions were performed in a submaximal way to acquire momentum, while the 6 following repetitions were maximal.

**Please, Figure 2a, Figure 2b, and Figure 2c here**

**Statistical analysis**

Statistical analyses were performed by SPSS software version 20 for Windows 7 (Chicago, USA). Data were presented as mean ± SD. The test–retest reliability was assessed using an intraclass correlation coefficient (ICC) two-way mixed model and interpreted as follows: ≥ 0.9 = *excellent*; ≥ 0.8 = *good*; ≥ 0.7 = *acceptable*; ≥ 0.6 = *questionable*; ≥ 0.5 = *poor*; < 0.5 = *unacceptable* (1). Shapiro-Wilk test was used for checking the normality (assumption). Analysis of covariance (ANCOVA), using baseline values as covariate, was employed to detect possible between-groups differences (14). When significant F-values were found, post hoc analysis was performed (with Bonferroni corrections applied to the alpha value). Statistical significance was set at p < 0.05. Robust estimates of 95% Confidence intervals (CI) of delta difference were calculated using bootstrapping technique (1000 randomly bootstrapped samples) (13). Effect size (ES) based on the Cohen d principle were reported with 95% CI and interpreted as: *trivial* < 0.2; 0.2 ≤ *small* < 0.6; 0.6 ≤ *moderate* < 1.2; 1.2 ≤ *large* < 2.0; *very large* > 2.0 (14).

**RESULTS**

No between groups differences were found on COD-5mD (F = 0.38, p = 0.686) and on COD-5mND (F = 0.99, p = 0.382). Groups (INC, EXT, SQU) and time (baseline and post) variations on COD-5mD and COD-5mND are reported in Figure 3.

**Please, Figure 3 here**

No statistically significant differences between groups for COD-5mD (F = 0.22, p = 0.804) and COD-5mND (F = 0.55, p = 0.583) data. Differences within (time) were found on COD-5mD (F = 22.09, p < 0.001) and on COD-5mND (F = 18.43, p < 0.001).

COD-5mD reported a significant difference after INC (p = 0.024, ES = 0.80, *moderate*), EXT (p = 0.043, ES = 0.74, *moderate*), and SQU (p = 0.002, ES = 1.42, *large*), and COD-5mND reported a significant difference after INC (p = 0.022, ES = 0.81, *moderate*), EXT (p = 0.030, ES = 0.81, *moderate*), and SQU (p = 0.047, ES = 0.72, *moderate*).

**Table 1, Table 2 and Table 3 here, please**

Statistically significant differences from baseline to post-EOL exercises were found in TMG variables: VL Dm (F = 22.24, p < 0.001), VL Tc (F = 1.49, p = 0.232), VL Td (F = 12.55, p < 0.001), VL V10 (F = 14.90, p < 0.001), VL V90 (F = 17.93, p < 0.001), VM Dm (F = 1020, p < 0.001), VM Tc (F = 0.53, p = 0.473), VM Td (F = 10.91, p = 0.003), VM V10 (F = 4.22, p = 0.049), VM V90 (F = 6.14, p = 0.020), RF Dm (F = 13.48, p = 0.001), RF Tc (F = 47.39, p < 0.001), RF Td (F = 29.14, p < 0.001), RF V10 (F = 6.11, p = 0.020), and RF V90 (F = 8.74, p = 0.006). A Post hoc analysis within (time) on VL, VM, and RF, for groups (INC, EXT, SQU) were reported in Table 1, Table 2 and Table 3, respectively.

Statistically significant differences between groups (INC, EXT, SQU) were not found on VL Dm (p = 0.686), VL Tc (p = 0.212), VL Td (p = 0.219), VL V10 (p = 0.607), VL V90 (p = 0.74), VM Dm (p = 0.096), VM Tc (p = 0.474), VM Td (0.893), VM V10 (p = 0.098), VM V90 (p = 0.113), RF Dm (p = 0.654), RF Tc (p = 0.258), RF Td (p = 0.969), RF V10 (p = 0.610), or RF V90 (p = 0.636). Therefore, post-hoc analysis between groups was not performed.

**DISCUSSION**

This study reported a significant positive PAP response on COD-5mD and COD-5mND after 4 min of recovery after INC, EXT and SQU exercises; a time effect has been found for TMG variables such as Dm and Td in VM, VL, and RF; however, such COD and muscular function changes are independent of pre-load exercise type (exercise groups). This study reports that COD performance improvements may be related to augmented muscle contractile functions and such improvement is independent from the pre-load activity used; therefore, researchers and practitioners should consider these new findings to develop suitable conditioning methods and maximize PAP responses before competitions and during training sessions.

The current study evaluated the PAP effect (after a recovery of 4 min) of three flywheel exercises (INC, EXT, SQU) showing significant improvements in COD-5mD and COD-5mND. In detail, EOL exercises reported a positive PAP (time) effect in COD-5mD after INC (ES = 0.80, *moderate*), EXT (ES = 0.74, *moderate*), and SQU (ES = 1.42, *large*), while in COD-5mND effects were reported after INC (ES = 0.81, *moderate*), EXT (ES = 0.81, *moderate*), and SQU (ES = 0.72, *moderate*). Such findings are commensurate with the current literature that supports the positive EOL effect on acute performance enhancements (6,27,35). A previous study has reported a PAP effect on vertical jump height and vertical peak power after an EOL exercise (6), as well as COD and short sprint time following a flywheel-based exercise involving male soccer players (15). Furthermore, a recent study found performance improvements after 3 to 6 min of passive recovery following an EOL PAP protocol on jumping (vertical and long jump) and COD performance (5), which confirm the results of the current study.

A proposal based upon previous research is that the PAP response may be specific to the pre-load protocol, since kinetic responses and therefore COD performance may be associated with the specific directional loading nature of the pre-load exercises (*e.g.* horizontal loading during INC vs. vertical loading during SQU) (17). For this reason, INC exercise may be suggested to be more effective than SQU or EXT exercise, while SQU may be more effective than EXT (since this exercise is not movement specific) for stimulating acute COD performance. However, there were no significant differences among INC, EXT, and SQU exercises, therefore each pre-load activity should be considered equivalent in such circumstances. This is the first study analyzing this theory using EOL protocols, thus a comparison with previous research is not possible. Considering the current results, further research is needed to investigate the effects of exercise modalities (specificity of the conditioning exercises) on subsequent performance.

Skeletal muscle contractile properties (*e.g.* Dm and Td) of the lower extremity (*e.g.* VL) can be determined using the non-invasive TMG method (21). Dm has been proposed as a measure of muscle belly stiffness, while Tc and Td are temporal TMG parameters (26). In the current study, Dm, Tc, Td, V10, and V90 reported variations following EOL exercises. Thus muscle contractile properties may contribute to explaining the PAP effect found in this study. Previously, it was suggested that decreased stiffness (increase in Dm) in the musculotendinous unit would induce a loss of force-generation and muscle power; *vice versa* an increment in stiffness should be associated with muscle contractile benefits (19). However, a decrement in Tc and Td has been found relating to the faster reaction of muscles to the electrical stimuli (40) following a PAP protocol. The lower Dm values found following the EOL protocol support an increment in muscle stiffness and therefore in force and power generation (40), which could explain the enhancement in COD performance. Moreover, the lower Tc and Td values reported may explain an increased (acute) muscle reactivity to signal transmission. This rationale is supported by Zubac et al. (40), who found a negative correlation between vertical jump changes and both muscle Tc (r = -0.56) and myosin heavy-chain type 1 following chronic training adaptations. The current study reports for the first time that such acute variations related to muscle contractile properties were muscle and exercise specific. For example, acute changes in VL Dm and RF Dm were *large* after INC, while they were *trivial* and *moderate* after SQU. Furthermore, RF V10 and RF V90 changes were *moderate* after SQU, while they were *small* following EXT. Nevertheless, the current study has reported a lack of between-group differences in muscular contractile functions (*e.g.* Tc, Td, Dm). Therefore, authors cannot speculate any PAP exercise-based superiority in muscle contractile properties variations. Notwithstanding this evidence, future research is necessary to better understand the optimal PAP responses following different exercises and its effect on TMG.

The current study is not without limitations. Firstly, this study compared three different EOL exercises without finding significant differences among the exercises. Further research is needed to clarify the PAP responses following different exercise modalities such as intensity (*e.g.* lower vs. higher inertia) and modality (*e.g.* SQU vs. EXT). Secondly, this study enrolled a sample of amateur male soccer players, therefore wider generalization cannot be inferred to other samples such as professional male and female athletes. This is a significant factor to take into consideration since stronger athletes have reported a different PAP time window and greater magnitude responses (7). Furthermore, this study reported an increment in COD performance after 4 min of recovery. Additional evidence is needed to better clarify the optimal PAP time window related to these specific exercises. Moreover, further research is required to better clarify the physiological factors that are related to (and can explain) PAP during sport specific tasks such as COD.

In conclusion, this study reported that INC, EXT and SQU exercises increase COD performance after 4 min of recovery in male soccer players. Muscle contractile functions assessed by TMG are acutely affected by EOL exercises, but as with COD performance, such differences are not group related. This study did not find differences between exercises on PAP magnitude which has been a surprising result considering the specific directional loading nature of the pre-load exercises.

**PRACTICAL APPLICATIONS**

Considering the results of this study, practitioners may use any of the EOL exercises reported in this study to acutely stimulate their athletes before competitions or during complex training methodologies. This study supports the use of such EOL exercises 4 min before the sport specific task. Considering the limited knowledge related to the specific PAP time window, authors suggest performing the sport specific task (*e.g.* COD) between 4 min (supported by the current research) and 10 min (based on previous research) after the EOL protocol. Each of the exercises utilized in this study has been reported to be an effective preload strategy to increase COD performance and considering previous evidence, authors suggest to use such exercises also to enhance jumping performance (5,6), although further research is needed. The EOL exercises used in this study have each reported similar time effects and muscle contractile function variations. Thus the authors cannot speculate any PAP exercise modality-based superiority. Additional research is needed to better clarify the differences in PAP magnitude between exercises since this study has not reported group differences. Furthermore, it has been reported (for the first time) that EOL exercises acutely affect TMG variables (*e.g.* Tc and Td) in lower limbs. These results are particularly interesting since muscle contractile functions are acutely affected by EOL exercises and may contribute to explaining the PAP effect. Further research is needed to better clarify the contribution on PAP phenomenon of physiological mechanisms such as cross-bridge attachments, increased sensitivity of contractile proteins to Ca2+, and neural factors.

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