

1 **Effects of post-activation potentiation after an eccentric overload bout on**  
2 **countermovement jump and lower-limb muscle strength.**

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1 **Effects of post-activation potentiation after an eccentric overload bout on**  
2 **countermovement jump and lower-limb muscle strength.**

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7 **Abstract**

8 The present study aimed to evaluate the post-activation potentiation (PAP) effects of an  
9 eccentric overload (EOL) exercise on countermovement jump (CMJ) performance and  
10 isokinetic lower-limb muscle strength. Eighteen active male (mean  $\pm$  SD, age  $20.2 \pm 1.4$   
11 years, body mass  $71.6 \pm 8$  kg, height  $178 \pm 7$  cm) were involved in a randomized, cross-over  
12 study. The participants performed 3 sets per 6 repetitions of EOL half squats at maximal  
13 power using a flywheel ergometer. PAP using an EOL exercise **was** compared with a control  
14 condition (10 min cycling at  $1 \text{ W}\cdot\text{kg}^{-1}$ ). CMJ height, peak power, impulse and force were  
15 recorded at 15s, 1, 3, 5, 7 and 9 min following an EOL exercise or control. Furthermore,  
16 quadriceps and hamstrings isokinetic strength **were** performed. PAP vs. control reported a  
17 meaningful difference for CMJ height after 3 min (ES = 0.68,  $p = 0.002$ ), 5 min (ES = 0.58,  $p$   
18 = 0.008), 7 min (ES = 0.57,  $p = 0.022$ ) and 9 min (ES = 0.61,  $p = 0.002$ ), peak power after 1  
19 min (ES = 0.22,  $p = 0.040$ ), 3 min (ES = 0.44,  $p = 0.009$ ), 5 min (ES = 0.40,  $p = 0.002$ ), 7 min  
20 (ES = 0.29,  $p = 0.011$ ), and 9 min (ES = 0.30,  $p = 0.008$ ), as well as quadriceps concentric,  
21 hamstrings concentric and hamstrings eccentric peak torque (ES = 0.13,  $p = 0.001$ , ES = 0.24,  
22  $p = 0.003$ , and ES = 0.22,  $p = 0.003$ , respectively) after 3 to 9 min rest. In conclusion, the  
23 present outcomes highlight that PAP using an EOL bout improves height, peak power,  
24 impulse and peak force during CMJ, as well as quadriceps and hamstrings isokinetic strength  
25 in male athletes. Moreover, the optimal time window for the PAP was found from 3 to 9  
26 minutes.

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58 **Keywords:** warm-up; power; flywheel; isokinetic; quadriceps; hamstrings  
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## 27 Introduction

1  
2 28 Post-activation potentiation (PAP) refers to a phenomenon associated with an acute  
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4 29 improvement in muscular performance following a warm-up strategy or a strength exercise  
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7 30 protocol, i.e. a preload stimulus (15,16). Although its underlying mechanisms are still  
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9 31 unknown, previous studies reported that neuromuscular, mechanical and biochemical changes  
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11 32 could induce these temporary improvements in performance (6,21,27). The most accredited  
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13 33 physiological explanation is associated with the phosphorylation of the myosin regulatory  
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15 34 light chains during a muscle contraction, which leads to a greater rate of cross-bridge  
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17 35 attachment (3,15). This is due to an increased sensitivity of the contractile proteins to calcium  
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19 36 ( $\text{Ca}^{2+}$ ), which is released from the sarcoplasmic reticulum and the subsequent muscle  
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21 37 response (e.g. twitch force and rate of force development) results increased (1–3). Other  
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23 38 evidence has reported that greater motor unit recruitment (higher post-synaptic potentials and  
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25 39 H-wave) could also affect the PAP (1). These factors play a critical role in the acute  
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27 40 improvements of mechanical power and consequent athletic performance following a preload  
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29 41 stimulus (13).

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31 42 PAP protocols have been used to acutely improve performance in competitions and  
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33 43 training sessions (25) as a warm-up to increase the voluntary explosive actions (18). Such  
34  
35 44 acute improvements in performance were shown to persist up to 10 min (1,3). In the literature,  
36  
37 45 several methods to induce PAP in athletes and untrained people are described, such as  
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39 46 dynamic or isometric strength exercise, cycling and sport specific warm-up (19,27). Previous  
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41 47 evidence reported that dynamic-constant external load exercise protocols increased the  
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43 48 muscular power after a bout of heavy or by light resistance exercise (1). In addition, maximal  
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45 49 isometric voluntary contractions have induced a PAP and subsequent improvements in the  
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47 50 rate of force development (2). It was reported that heavy resistance exercise improved  
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49 51 repeated sprint ability in adult handball players (25) and youth athletes (19). Similar  
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52 improvements have been reported in linear sprint in adult soccer players (21) and women  
53 college sprinters (100 m) (18). Parallel back squat (1 x 5 RM) showed to potentiate  
54 performance in sprints and jumps in active men (5,28). Back squat exercise using heavy load  
55 (4 x 90% of 1RM) and moderate load (6 x 60% of 1RM) reported PAP to countermovement  
56 jump (CMJ) performance in resistance trained male subjects (3).

57 Eccentric overload (EOL) exercise is a methodology used to improve sports  
58 performance and it is commonly generated by flywheel devices (15,29). During an EOL  
59 exercise, the concentric phase is weight-free and the eccentric phase is enhanced by the inertia  
60 accumulated during the concentric phase (12,15). Higher electromyographic activity has been  
61 reported during a EOL bout compared with traditional weight exercise (24). EOL training has  
62 shown important practical applications for strength conditioning coaches. For example, it has  
63 been reported that EOL elicits improvements in strength and power that play a functional role  
64 in most of the required movements in sport (15,20). However, most studies published to date  
65 had a focus on chronic adaptations (20,24,30), while only a few have analyzed the acute  
66 benefits of PAP following an EOL protocol (13,29). Recent studies have reported that PAP  
67 developed by EOL improved jump and 20 m sprint performance in highly training soccer  
68 players (15), as well as meaningful improvements in horizontal velocity (5 m and 15 m) and  
69 angular velocity of knee extension in swimmers (13). Studies on PAP found positive  
70 performance improvements after strength exercises (using traditional pre-load strategies),  
71 while others have failed to confirm these results (3,18,21). These inconsistent findings could  
72 be ascribed to the several factors that affect the PAP response such as training volume,  
73 intensity, rest duration and time windows following the exercise protocol (1).

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74 Counter movement jump (CMJ) is a method to evaluate lower-limb muscle power, as  
75 well as previous studies have reported the validity of isokinetic tests to evaluate lower-limb  
76 muscle strength (4,10,32). Particularly, both quadriceps and hamstrings strength are crucial

77 for several sports activities(10) and their balance may help to prevent hamstring injury (11).  
78 To date, there is not any evidence about the acute effects of EOL bout on CMJ performance  
79 and lower-limb muscle strength. Moreover, no data are available regarding the PAP time-  
80 course as well as the magnitude of the effects using a flywheel device. This information could  
81 be critical for the development of strength training strategies and power optimization before a  
82 training session or a competition. Therefore, the aim of the present study was to evaluate the  
83 effects of PAP of an EOL exercise (half squat) vs a traditional warm up on CMJ performance  
84 (jump height, peak power, impulse and force) and quadriceps and hamstrings isokinetic  
85 strength in male athletes.

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## 87 **Methods**

### 88 **Experimental approach to the problem**

89 The acute effects induced by EOL (experimental condition) vs. a traditional warm-up  
90 (control condition) on CMJ performance and isokinetic peak torque were investigated in the  
91 present randomized, cross-over study design. Each participant attended the laboratory on five  
92 separate occasions. The first one served to familiarize participants with the EOL exercise, the  
93 CMJ and the isokinetic testing procedures. Within the remaining four sessions, the  
94 participants performed one of the four testing protocols in a randomized order: CMJ tests  
95 following a standardized warm-up (control), isokinetic assessments following a standardized  
96 warm-up (control) and CMJ tests following a standardized warm-up and EOL exercise  
97 (experimental condition) and isokinetic assessments following a standardized warm-up and  
98 EOL exercise (experimental condition).

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### 100 **Subjects**

101 Eighteen active male were enrolled in this study (mean  $\pm$  SD; age  $20.2 \pm 1.4$  years,  
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2 102 body mass  $71.6 \pm 8$  kg, height  $178 \pm 7$  cm). Inclusive criteria for participation were the  
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4 103 absence of any injury or illness (PAR-Q), a regular training activity with a minimum of 3  
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7 104 training session per week and a regular participation to competitions (athletes of different  
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9 105 sport background were enrolled such as soccer, American football, rugby). All participants  
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12 106 were informed about the potential risks and benefits of the current procedures and signed an  
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14 107 informed consent. The Ethics Committee of the School of Science, Technology and  
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17 108 Engineering, University of Suffolk (UK) approved this study. All procedures were conducted  
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19 109 according to the Declaration of Helsinki for studies involving human subjects. To calculate  
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22 110 the sample size, statistical software (GPower, Dusseldorf, Germany) was used. Given the  
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24 111 study 2-way ANOVA (2 group, and 6 repeated measures), a medium overall effect size  $f =$   
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26 112  $0.25$ , an  $\alpha$ -error  $< 0.05$ , and a desired power ( $1-\beta$  error)  $= 0.8$ , the total sample size resulted in  
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29 113 fifteen participants. To prevent the effects of any possible dropout on the statistical power,  
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31 114 eighteen participants were included.

## 36 116 **Procedures**

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39 117 Body mass and height were recorded by Stadiometer (Seca 286dp, Hamberg,  
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41 118 Germany). A standardized warm-up including 10 min of cycling at a constant power (1 W per  
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43 119 Kg of body mass) on an ergometer (workload range of 8-2500 W, Sport Excalibur lode,  
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46 120 Groningen, Netherland) and dynamic mobilization was performed in both the control and  
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48 121 experimental conditions (3).

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51 122 Two sessions were performed as control where participants performed CMJ tests  
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53 123 (control session 1) and an isokinetic test (control session 2) after the conclusion of the warm-  
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56 124 up without any additional strength exercise. The same warm-up previously described (10 min  
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58 125 of cycling at a constant power) was used on each occasion. CMJ tests were performed  
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126 immediately after the end of the warm-up at 15 s, 1 min, 3 min, 5 min, 7 min and 9 min. This  
 127 jump series were conducted during each of the subsequent conditions (control and  
 128 experimental). Isokinetic test was performed between 3 and 9 minutes after the end of the  
 129 warm-up. This time window has been utilized to optimize the effects of PAP as previously  
 130 reported (2,3,27).

131 The experimental condition used the same procedure described for the control but  
 132 involving also an EOL exercise after the warm-up. Therefore, the CMJ protocol was  
 133 performed immediately after EOL exercise (experimental session 1) as well as the isokinetic  
 134 evaluations (experimental session 2).

135 Please figure 1 here.

### 137 *Counter movement jump*

138 CMJ was assessed using a force platform (Kistler, Winterthur, Switzerland) using a  
 139 sampling rate of 1000 Hz (22). The participants were instructed to stand, lower themselves to  
 140 a self-selected knee flexion and immediately jump and were encouraged to maximally  
 141 perform each jump. The participants were instructed to avoid any knee-flexion before the  
 142 landing and to keep their hands on their hips to prevent the influence of arm movements on  
 143 vertical jump performance, under the supervision of an experienced operator. The following  
 144 variables were inserted into the data analysis: jump height (cm), peak power (W), impulse  
 145 (N·Kg) and peak jumping force (N). *Excellent* test-retest reliability was found for each  
 146 parameter:  $\alpha = 0.910$ ,  $\alpha = 0.922$ ,  $\alpha = 0.918$ ,  $\alpha = 0.901$ . Jump height was defined as the vertical  
 147 displacement achieved by the center of mass from take-off to the vertex of the flight trajectory  
 148 using time in the air (TIA):

$$150 \quad \text{TIA jump height} = \frac{1}{2} g (t / 2)^2$$

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1  
2 152 where  $g = 9.81 \text{ m} \cdot \text{sec}^{-2}$ ,  $t = \text{time in air (23)}$ .

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### 7 154 *Isokinetic testing assessment*

9 155 An isokinetic dynamometer (Biodex Medical Systems, Shirley, NY, USA) was used to  
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12 156 measure the quadriceps and hamstrings strength. The procedures followed previous  
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14 157 recommendations (9,17): briefly, the device was calibrated according to the manufacturer's  
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17 158 procedures and the center of rotation was aligned with the tested knee. The participants were  
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19 159 seated on the dynamometer chair, with their trunks slightly reclined backwards and a hip  
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22 160 angle of  $95^\circ$ . Two seatbelts secured the trunk and one strap secured the tested limb, while the  
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24 161 untested limb was secured by an additional lever. The quadriceps peak torque was measured  
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26 162 in concentric ( $60^\circ \cdot \text{s}^{-1}$ ) and the hamstrings peak torque was measured in concentric ( $60^\circ \cdot \text{s}^{-1}$ )  
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29 163 and eccentric ( $-60^\circ \cdot \text{s}^{-1}$ ) modality. Each testing-modality consisted of three maximal trials and  
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31 164 was separated by 2 min of passive recovery. Strongly standardized encouragements were  
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34 165 provided to the participants to maximally perform each trial (11,17). The peak torque was  
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36 166 then calculated and inserted into the data analysis. Finally, the hamstrings-to-quadriceps  
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39 167 strength ratio, defined as the ratio between eccentric hamstrings-to-concentric quadriceps  
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41 168 peak torque (i.e., conventional  $H_{\text{conc}}:Q_{\text{conc}}$  ratio and functional  $H_{\text{ecc}}:Q_{\text{conc}}$  ratio) was also  
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44 169 calculated (11,26). The dominant limb, defined as the preferred limb used to kick the ball,  
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46 170 was tested (2,3). *Excellent* test-retest reliability was found for all the isokinetic measurements  
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48 171 ( $\alpha = 0.900 - 0.944$ )  
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### 53 173 *Intervention*

55 174 EOL was performed by a half squat exercise using a flywheel ergometer (D11 full,  
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58 175 Desmotec, Biella, Italy). The PAP protocol consisted of 3 sets x 6 repetitions of half squats at  
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176 maximal power, interspersed by 2 min of passive recovery. Each movement was evaluated by  
177 an operator that offered a feedback to the athletes during the EOL exercise. The following  
178 combined load was used for each participant: one large disk (diameter = 285 mm, mass = 1.9  
179 Kg, inertia =  $0.02 \text{ kg}\cdot\text{m}^2$ ) and one medium disk (diameter = 240 mm, mass = 1.1 kg, inertia =  
180  $0.008 \text{ kg}\cdot\text{m}^2$ ). The inertia of the machine (D11) was estimated as  $0.0011 \text{ kg}\cdot\text{m}^2$ . The  
181 participants were instructed to perform the concentric phase as fast as possible and to control  
182 the braking phase until the knees where flexed up to approximately  $90^\circ$ . An investigator  
183 offered a technique feedback for each repetition. The participants received strong  
184 standardized encouragements to maximally perform each repetition.

## 186 **Statistical analysis**

187 Statistical analyses were performed by SPSS software version 20 for Windows 7,  
188 Chicago, USA. Data were presented as mean  $\pm$  standard deviation (SD). The test-retest  
189 reliability was measured using an ICC (Cronbach- $\alpha$ ) and interpreted as follows:  $\alpha \geq 0.9 =$   
190 *excellent*;  $0.9 > \alpha \geq 0.8 = \textit{good}$ ;  $0.8 > \alpha \geq 0.7 = \textit{acceptable}$ ;  $0.7 > \alpha \geq 0.6 = \textit{questionable}$ ;  $0.6$   
191  $> \alpha \geq 0.5 = \textit{poor}$ ;  $\alpha < 0.5 \textit{ unacceptable}$  (10). One-way repeated measure analysis of variance  
192 (ANOVA) was used to evaluate the effects of condition (Control vs PAP) on CMJ height,  
193 peak power, impulse and force. If a meaningful F-value was found, the Bonferroni correction  
194 was applied. Paired t-test was performed between Control vs PAP for the isokinetic  
195 parameters. Robust estimates of 90% confidence interval (CI) (14) and heteroskedasticity  
196 were calculated using bootstrapping technique (randomly 1000 bootstrap samples).  
197 Significance was set at  $p < 0.05$  and reported to indicate the strength of the evidence. The  
198 effect size (ES) was calculated and interpreted as follows:  $< 0.20$ : *trivial*,  $0.20-0.59$ : *small*,  
199  $0.60-1.19$ : *moderate*,  $1.20-1.99$ : *large*,  $\geq 2.00$  *very large* (14).

## 201 Results

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2 202 The between-group analysis reported differences in CMJ height ( $F = 20.8, p < 0.001$ ),  
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4 203 power ( $F = 11.5, p = 0.003$ ), impulse ( $F = 6.5, p = 0.020$ ) and force ( $F = 10.6, p = 0.005$ ). The  
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7 204 post-hoc Control *vs* PAP conditions on jump and power data are reported in table 1, while  
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9 205 impulse and force data are reported in table 2.

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14 207 Please table 1 and table 2 here  
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19 209 The isokinetic analysis reported meaningful variations between the PAP and control  
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22 210 conditions for quadriceps concentric **peak torque** ( $t = 4.3, p = 0.001$ ), hamstrings concentric  
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24 211 **peak torque** ( $t = 3.5, p = 0.003$ ), hamstrings eccentric peak torque ( $t = 3.5, p = 0.003$ ),  
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26 212  $H_{\text{conc}}:Q_{\text{conc}}$  ratio ( $t = 1.8, p = 0.083$ ) and  $H_{\text{ecc}}:Q_{\text{conc}}$  ratio ( $t = 3.8, p = 0.001$ ). The PAP *vs*  
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29 213 control isokinetic data are reported in table 3.  
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34 215 Please insert table 3 here  
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## 38 217 Discussion

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41 218 In the literature, no evidence of the acute effects of EOL bout on CMJ performance  
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43 219 and isokinetic strength exists to date. Moreover, no data are currently available regarding the  
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46 220 optimal PAP time windows, as well as the magnitude of the effects following an EOL  
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48 221 exercise. To the best of the authors' knowledge, the current study was the first to evaluate  
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51 222 such parameters after a squat exercise performed using an EOL. Compared to control, greater  
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53 223 CMJ height were observed after 3 min, 5 min, 7 min, and 9 min. Similarly, peak power was  
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56 224 greater after 1 min, 3 min, 5 min, 7 min, and 9 min. The CMJ impulse increased after 5 min, 7  
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58 225 min, and 9 min, as well as CMJ force after 5 min, 7 min, and 9 min. In addition, greater  
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226 quadriceps concentric **peak torque**, hamstrings concentric **peak torque**, eccentric peak torque,  
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2 227 functional  $H_{ecc}:Q_{conc}$  ratio were observed but not in conventional  $H_{conc}:Q_{conc}$  ratio.  
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4 228 PAP is defined as a transient increase in muscle performance following a pre-load  
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7 229 strategy (6). It was shown that neuromuscular, mechanical and biochemical mechanisms  
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9 230 could be behind these temporary improvements in performance (21). Stiffness is related to the  
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12 231 number and the stability of the bonds between actin and myosin filaments. Following a pre-  
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14 232 load activity, many of these bonds are broken and the passive stiffness decreases, which can  
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17 233 cause an improvement in performance (6). A further explanation reported in literature is  
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19 234 related to the myosin regulatory light chains function that renders the actin–myosin  
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22 235 interaction more sensitive to calcium and causes conformational changes of the myosin head,  
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24 236 which during a muscle contraction leads to a greater rate of cross-bridge attachment (3,8,15).  
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26 237 This mechanism is due to an increased sensitivity in the contractile proteins to calcium ( $Ca^{2+}$ ),  
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29 238 which is released from the sarcoplasmic reticulum, and the subsequent muscle repose results  
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31 239 improved (1–3,6,7). Such motivations could explain the improvement in muscle power and  
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34 240 rate of force development following a pre-load strategy (6). Moreover, a major recruitment of  
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36 241 higher order motor units (higher post-synaptic potentials and H-wave) through a decreased  
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39 242 threshold of activation for the fast-twitch motoneurons during both maximal and submaximal  
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41 243 exercise seems to increase the PAP (1,8). The current results agree with previously reported  
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44 244 literature using an EOL bout, which has found *small* differences vs control in CMJ height and  
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46 245 20 m sprint time (15). Moreover, the present findings are in line with the higher peak force  
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49 246 and speed reported following an EOL protocol compared to a control condition in swimming  
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51 247 athletes (13). The differences found here support previous findings where acute positive  
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53 248 effects of heavy traditional resistance exercise on performance in horizontal and vertical **jump**  
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56 249 (28) and time on 5 m and 10 m sprint were observed in professional athletes (5). Finally, the  
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58 250 present results agree with a previous study where a *moderate* increment in vertical ground  
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251 reaction force and propulsive force and a *small* increment in total impulse were found  
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2 252 following an EOL-based warm-up during a change of direction exercise (15). Therefore,  
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4 253 based on the current results and previous evidence, an EOL bout is a valid exercise to  
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7 254 stimulate PAP and consequently to over-stimulate the lower-limb muscle power.  
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9 255 The current study has not observed any PAP *vs.* Control difference in jump height,  
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12 256 peak power, impulse and peak force at 15 s, as well as in impulse and peak force at 1 min.  
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14 257 The current findings agree with a previous study that found a decrement in CMJ height  
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17 258 immediately after a back squat exercise (3). This supports that PAP could be related to time-  
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19 259 dependent factors (13,27). Following a conditioning activity (e.g. pre-load), fatigue is  
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22 260 dissipated quicker than PAP, thus potentiation allows subsequent increments in performance  
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24 261 (e.g. power) (1). The acute fatigue following the EOL exercise could have affected the jump  
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27 262 kinematic, as previously reported in swimmers (13). Fatigue is more dominant in the early  
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29 263 stage of recovery but it diminishes at a quicker rate than PAP, therefore the potentiation of  
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32 264 performance may be realized during the following recovery period (1). Previous evidence  
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34 265 reported that the optimal time to the PAP development is from 3 to 10 min after the exercise  
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36 266 (3,5). The present study supports such data, reporting a *moderate* difference *vs* control in CMJ  
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39 267 height and a *small* one in peak power after 3 min of passive recovery. However, impulse and  
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41 268 peak force differed from control mainly after 5 min of passive recovery This would support  
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44 269 that an optimal time window to maximize the performance after the PAP exists (28).  
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46 270 The present study utilized an isokinetic device to evaluate the effects of the PAP on  
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49 271 the lower-limb muscle strength. This study found a *trivial* meaningful difference in  
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51 272 quadriceps concentric and *small* differences in hamstrings concentric and eccentric peak  
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53 273 torque *vs* control. However, since this is the first study that investigated these specific acute  
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56 274 isokinetic strength responses, a direct comparison with previous literature is challenging. The  
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58 275 strength difference reported in the current study following an EOL PAP protocol *vs* control  
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276 could be explained considering the high muscle activation (e.g. increased neural drive) and  
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2 277 the mechanical stress obtained by EOL exercise (20,24,29). An enhanced neural drive could  
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4 278 be related to a superior motor cortex activation compensating for the spinal inhibition during  
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7 279 eccentric phase (31). The positive effect of PAP on lower-limb muscle strength could have  
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10 280 several practical implications, since the lower-limb isokinetic peak torque was found to be  
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12 281 correlated with changes of direction, sprinting and jumping abilities in elite soccer players  
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14 282 (10).

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17 283         Interestingly, a *moderate* and a *small* difference in the  $H_{conc}:Q_{conc}$  and  $H_{ecc}:Q_{con}$  ratio  
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19 284 respectively was observed *vs* control, i.e. the hamstrings concentric and eccentric peak torque  
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21 285 improved more than the quadriceps concentric peak torque. This might depend on the greater  
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24 286 overload demanded during the eccentric than the concentric phase (20). Indeed, a greater  
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26 287 hamstrings *vs* quadriceps activity was reported during the eccentric *vs* concentric phase of a  
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29 288 squat exercise (33). Consequently, the enhanced-eccentric phase may have highlighted this  
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31 289 specific hamstring *vs* quadriceps activity. These findings are particularly interesting since the  
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34 290 hamstrings-to-quadriceps strength ratio has been linked to injury risk and sport-specific  
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36 291 performance (10,11). Since fatigue was shown to decrease the  $H_{ecc}:Q_{con}$  ratio (11), the current  
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39 292 results may offer a temporary protection for both training sessions and performance  
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41 293 enhancing the strength of the hamstrings (11). However, some negative effects associated  
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44 294 with the temporary fatigue following an EOL PAP protocol (1,2), as well as the short-term  
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46 295 muscle damage induced by the eccentric exercise should be considered (12).

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48 296         The current study presents some limitations. Firstly, the present study involved active  
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51 297 men only. Therefore, wider generalization cannot be inferred and the results could not be  
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53 298 extended to other specific populations (e.g. elite female athletes). Secondly, vertical jump has  
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56 299 been estimated using TIA and not calculated by kinematic data. Additionally, it was shown  
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58 300 that the fitness level may account for the amount of the PAP response. Indeed, a previous  
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301 study found major benefits in strength-trained vs recreational active participants (5). Future  
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2 302 studies could replicate the current procedures enrolling a different population. Moreover,  
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4 303 future studies are necessary to better evaluate the PAP effects on sport-specific performance  
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7 304 considering that PAP response presents large variability among subjects, as well as the known  
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9 305 responder versus non-responder phenomenon (3,5).

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14 307 In conclusion, the present study suggests that an EOL bout increases the jump height, peak  
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16 308 power, impulse and peak force during a CMJ, as well as the quadriceps and hamstrings  
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19 309 isokinetic strength in male athletes. Moreover, the optimal time window for the PAP was  
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21 310 found here from 3 to 9 minutes, although some increments could be possible after 1 min of  
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24 311 passive recovery.

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### 26 313 **Practical applications**

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29 314 The present outcomes could be utilized by coaches to optimize strength and power  
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31 315 development during training sessions (e.g. contrast training) and before the competition where  
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34 316 great power and strength are required (3,4,27). During contrast training, a high intensity  
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36 317 exercise (e.g. squat) can be associated with a plyometric or jump activity involving the same  
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39 318 muscle groups (27). The rationale of such training is to utilize the PAP developed during the  
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41 319 preload exercise to improve the performance of the movements selected (e.g. jumps and  
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44 320 sprints), which incorporated into long-term training programs could induce superior chronic  
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46 321 neuromuscular adaptations (3,5). Moreover, authors underline the importance to consider the  
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49 322 PAP time window reported in this study to optimize contrast training methodologies and  
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51 323 acute athletes' performance. Therefore, coaches should consider a rest period of 3 minutes to  
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54 324 optimize the contrast training strategies. Indeed, a minimal recovery period following an EOL  
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56 325 exercise seems to have a critical importance for jump performance and muscle strength.  
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2 327 **References**

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58 350

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64

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1. Anthony, N and Bishop, D. Factors Modulating Post-Activation Potentiation and its effects on performance. *Sport Med* 39: 147–166, 2009.
2. Baudry, S and Duchateau, J. Postactivation potentiation in a human muscle: effect on the rate of torque development of tetanic and voluntary isometric contractions. *J Appl Physiol* 102: 1394–401, 2007. Available from: <http://jap.physiology.org/cgi/doi/10.1152/jappphysiol.01254.2006>
3. Bauer, P, Sansone, P, Mitter, B, Makivic, B, Seitz, LB, and 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* 1, 2018. Available from: <http://insights.ovid.com/crossref?an=00124278-900000000-95563>
4. Beato, M, Bianchi, M, Coratella, G, Merlini, M, and 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. Available from: <http://insights.ovid.com/crossref?an=00124278-900000000-95631>
5. Bevan, HR, Cunningham, DJ, Tooley, EP, Owen, NJ, Cook, CJ, and Kilduff, LP. Influence of postactivation potentiation on sprinting performance in professional rugby players. *J strength Cond Res* 24: 701–5, 2010. Available from: <http://www.ncbi.nlm.nih.gov/pubmed/20145565>
6. Bishop, D. Warm up I: potential mechanisms and the effects of passive warm up on exercise performance. *Sports Med* 33: 439–54, 2003. Available from: <http://www.ncbi.nlm.nih.gov/pubmed/12744717>
7. Bishop, D. Warm up II: performance changes following active warm up and how to

- 351 structure the warm up. *Sports Med* 33: 483–98, 2003. Available from:  
 1  
 2 352 <http://www.ncbi.nlm.nih.gov/pubmed/12762825>  
 3  
 4 353 8. Bogdanis, GC, Tsoukos, A, and Veligekas, P. Improvement of Long-Jump  
 5  
 6  
 7 354 Performance During Competition Using a Plyometric Exercise. *Int J Sports Physiol*  
 8  
 9 355 *Perform* 12: 235–240, 2017. Available from:  
 10  
 11  
 12 356 <http://www.ncbi.nlm.nih.gov/pubmed/27249821>  
 13  
 14 357 9. Coratella, G, Beato, M, Milanese, C, Longo, S, Limonta, E, Rampichini, S, et al.  
 15  
 16  
 17 358 Specific Adaptations in Performance and Muscle Architecture After Weighted Jump-  
 18  
 19 359 Squat vs. Body Mass Squat Jump Training in Recreational Soccer Players. *J Strength*  
 20  
 21 360 *Cond Res* 32: 921–929, 2018. Available from:  
 22  
 23  
 24 361 <http://insights.ovid.com/crossref?an=00124278-900000000-95490>  
 25  
 26 362 10. Coratella, G, Beato, M, and Schena, F. Correlation between quadriceps and hamstrings  
 27  
 28  
 29 363 inter-limb strength asymmetry with change of direction and sprint in U21 elite soccer-  
 30  
 31 364 players. *Hum Mov Sci* 59: 81–87, 2018. Available from:  
 32  
 33  
 34 365 <https://doi.org/10.1016/j.humov.2018.03.016>  
 35  
 36 366 11. Coratella, G, Bellin, G, Beato, M, and Schena, F. Fatigue affects peak joint torque  
 37  
 38  
 39 367 angle in hamstrings but not in quadriceps. *J Sports Sci* 33: 1276–1282, 2015. Available  
 40  
 41 368 from: <http://www.tandfonline.com/doi/full/10.1080/02640414.2014.986185>  
 42  
 43 369 12. Coratella, G, Chemello, A, and Schena, F. Muscle damage and repeated bout effect  
 44  
 45  
 46 370 induced by enhanced eccentric squats. *J Sports Med Phys Fitness* 56: 1540–1546,  
 47  
 48 371 2016. Available from: <http://www.ncbi.nlm.nih.gov/pubmed/26671347>  
 49  
 50  
 51 372 13. Cuenca-Fernández, F, López-Contreras, G, and Arellano, R. Effect on swimming start  
 52  
 53 373 performance of two types of activation protocols: lunge and YoYo squat. *J strength*  
 54  
 55 374 *Cond Res* 29: 647–55, 2015. Available from:  
 56  
 57  
 58 375 <http://www.ncbi.nlm.nih.gov/pubmed/25226318>  
 59  
 60  
 61  
 62  
 63  
 64  
 65

- 376 14. Hopkins, WG, Marshall, SW, Batterham, AM, and Hanin, J. Progressive statistics for  
1 studies in sports medicine and exercise science. *Med Sci Sports Exerc* 41: 3–13,  
2 377  
3  
4 378 2009. Available from: <http://www.ncbi.nlm.nih.gov/pubmed/19092709>  
5  
6
- 7 379 15. de Hoyo, M, de la Torre, A, Pradas, F, Sañudo, B, Carrasco, L, Mateo-Cortes, J, et al.  
8  
9 380 Effects of eccentric overload bout on change of direction and performance in soccer  
10  
11 381 players. *Int J Sports Med* 36: 308–314, 2014. Available from: <http://www.thieme->  
12  
13 382 [connect.de/DOI/DOI?10.1055/s-0034-1395521](http://www.thieme-connect.de/DOI/DOI?10.1055/s-0034-1395521)  
14  
15
- 16 383 16. Dello Iacono, A, Martone, D, and Padulo, J. Acute Effects of Drop-Jump Protocols on  
17  
18 384 Explosive Performances of Elite Handball Players. *J strength Cond Res* 30: 3122–  
19  
20 385 3133, 2016. Available from: <http://www.ncbi.nlm.nih.gov/pubmed/26958786>  
21  
22
- 23 386 17. Impellizzeri, FM, Bizzini, M, Dvorak, J, Pellegrini, B, Schena, F, and Junge, A.  
24  
25 387 Physiological and performance responses to the FIFA 11+ (part 2): a randomised  
26  
27 388 controlled trial on the training effects. *J Sports Sci* 31: 1491–502, 2013. Available from:  
28  
29 389 <http://www.ncbi.nlm.nih.gov/pubmed/23855764>  
30  
31
- 32 390 18. Linder, EE, Prins, JH, Murata, NM, Derenne, C, Morgan, CF, and Solomon, JR.  
33  
34 391 Effects of preload 4 repetition maximum on 100-m sprint times in collegiate women. *J*  
35  
36 392 *strength Cond Res* 24: 1184–90, 2010. Available from:  
37  
38 393 <http://www.ncbi.nlm.nih.gov/pubmed/20386122>  
39  
40
- 41 394 19. Low, D, Harsley, P, Shaw, M, and Peart, D. The effect of heavy resistance exercise on  
42  
43 395 repeated sprint performance in youth athletes. *J Sports Sci* 33: 1028–1034,  
44  
45 396 2015. Available from: <http://dx.doi.org/10.1080/02640414.2014.979857>  
46  
47
- 48 397 20. Maroto-Izquierdo, S, García-López, D, Fernandez-Gonzalo, R, Moreira, OC,  
49  
50 398 González-Gallego, J, and de Paz, JA. Skeletal muscle functional and structural  
51  
52 399 adaptations after eccentric overload flywheel resistance training: a systematic review  
53  
54 400 and meta-analysis. *J Sci Med Sport* 20: 943–951, 2017. Available from:  
55  
56  
57  
58  
59  
60  
61  
62  
63  
64  
65

- 401 <http://dx.doi.org/10.1016/j.jsams.2017.03.004>
- 1  
2 402 21. McBride, JM, Nimphius, S, and Erickson, TM. The acute effects of heavy-load squats  
3  
4 403 and loaded countermovement jumps on sprint performance. *J strength Cond Res* 19:  
5  
6 893–7, 2005. Available from: <http://www.ncbi.nlm.nih.gov/pubmed/16287357>
- 7 404  
8  
9 405 22. Meylan, CMP, Nosaka, K, Green, J, and Cronin, JB. Temporal and kinetic analysis of  
10  
11 406 unilateral jumping in the vertical, horizontal, and lateral directions. *J Sports Sci* 28:  
12  
13 545–554, 2010. Available from:  
14 407  
15  
16 <http://www.tandfonline.com/doi/abs/10.1080/02640411003628048>
- 17 408  
18  
19 409 23. Moir, GL. Three different methods of calculating vertical jump height from force  
20  
21 platform data in men and women. *Meas Phys Educ Exerc Sci* 12: 207–218, 2008.  
22 410  
23  
24 411 24. Norrbrand, L, Pozzo, M, and Tesch, PA. Flywheel resistance training calls for greater  
25  
26 412 eccentric muscle activation than weight training. *Eur J Appl Physiol* 110: 997–1005,  
27  
28 2010. Available from: <http://www.ncbi.nlm.nih.gov/pubmed/20676897>
- 29 413  
30  
31 414 25. Okuno, NM, Tricoli, V, Silva, SBC, Bertuzzi, R, Moreira, A, and Kiss, M a. PDM.  
32  
33 Postactivation potentiation on repeated-sprint ability in elite handball players. *J*  
34 415  
35 *strength Cond Res* 27: 662–8, 2013. Available from:  
36 416  
37  
38 <http://www.ncbi.nlm.nih.gov/pubmed/22561976>
- 39 417  
40  
41 418 26. Rahnema, N, Reilly, T, Lees, A, and Graham-Smith, P. Muscle fatigue induced by  
42  
43 419 exercise simulating the work rate of competitive soccer. *J Sports Sci* 21: 933–42,  
44  
45 2003. Available from:  
46 420  
47  
48 <http://www.tandfonline.com/doi/abs/10.1080/0264041031000140428>
- 49 421  
50  
51 422 27. Robbins, DW. Postactivation potentiation and its practical applicability: a brief review.  
52  
53 423 *J strength Cond Res* 19: 453–8, 2005. Available from:  
54  
55 <http://www.ncbi.nlm.nih.gov/pubmed/15903390>
- 56 424  
57  
58 425 28. Scott, SL and Docherty, D. Acute effects of heavy preloading on vertical and  
59  
60  
61  
62  
63  
64  
65

- 426 horizontal jump performance. *J strength Cond Res* 18: 201–5, 2004. Available from:  
1  
2 427 <http://www.ncbi.nlm.nih.gov/pubmed/15142025>  
3  
4  
5 428 29. Tous-Fajardo, J, Gonzalo-Skok, O, Arjol-Serrano, JL, and Tesch, P. Enhancing  
6  
7 429 Change-of-Direction Speed in Soccer Players by Functional Inertial Eccentric  
8  
9 430 Overload and Vibration Training. *Int J Sports Physiol Perform* 11: 66–73,  
10  
11  
12 431 2016. Available from: <http://www.ncbi.nlm.nih.gov/pubmed/25942419>  
13  
14 432 30. Vicens-Bordas, J, Esteve, E, Fort-Vanmeerhaeghe, A, Bandholm, T, and Thorborg, K.  
15  
16  
17 433 Is inertial flywheel resistance training superior to gravity-dependent resistance training  
18  
19 434 in improving muscle strength? A systematic review with meta-analyses. *J Sci Med*  
20  
21  
22 435 *Sport* 21: 75–83, 2017. Available from: <http://dx.doi.org/10.1016/j.jsams.2017.10.006>  
23  
24 436 31. Wagle, JP, Taber, CB, Cunanan, AJ, Bingham, GE, Carroll, KM, DeWeese, BH, et al.  
25  
26  
27 437 Accentuated Eccentric Loading for Training and Performance: A Review. *Sports Med*  
28  
29 438 47: 2473–2495, 2017. Available from: <http://www.ncbi.nlm.nih.gov/pubmed/28681170>  
30  
31 439 32. Wisløff, U, Castagna, C, Helgerud, J, Jones, R, and Hoff, J. Strong correlation of  
32  
33  
34 440 maximal squat strength with sprint performance and vertical jump height in elite soccer  
35  
36 441 players. *Br J Sports Med* 38: 285–8, 2004. Available from:  
37  
38  
39 442 <http://www.ncbi.nlm.nih.gov/pubmed/15155427>  
40  
41 443 33. Yoo, W. Comparison of hamstring-to-quadriceps ratio between accelerating and  
42  
43  
44 444 decelerating sections during squat exercise. *J Phys Ther Sci* 28: 2468–2469, 2016.  
45  
46 445  
47  
48  
49  
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1 Table 1. Summary of Control and PAP jump and power data (n = 18). Data are presented in mean  $\pm$  SDs.

2

<b>Variable</b>	<b>Control</b>	<b>PAP</b>	<b>Delta difference</b>	<b>Effect size</b>	<b>p-level</b>	<b>Effect size</b>
	<b>Mean <math>\pm</math> SDs</b>	<b>Mean <math>\pm</math> SDs</b>	<b>(90% CI)</b>	<b>(90% CI)</b>		<b>assessment</b>
<b>Jumps height</b>						
Jump 15 s (cm)	32.9 $\pm$ 6.3	32.1 $\pm$ 7.0	-0.8 (-1.7; 0.1)	-0.12 (-0.24; -0.02)	0.096	Trivial
Jump 1 min (cm)	32.6 $\pm$ 5.7	35.3 $\pm$ 8.5	2.6 (0.9; 4.6)	0.47 (0.08; 0.86)	0.053	Small
Jump 3 min (cm)	33.4 $\pm$ 6.3	37.7 $\pm$ 8.7	4.2 (2.5; 6.1)	0.68 (0.35; 1)	0.002	Moderate
Jump 5 min (cm)	32.3 $\pm$ 6.2	36.9 $\pm$ 7.8	4.5 (2.1; 5.6)	0.58 (0.24; 0.92)	0.008	Small
Jump 7 min (cm)	32.1 $\pm$ 6.2	36.1 $\pm$ 8.2	3.9 (2.4; 5.6)	0.57 (0.18; 0.96)	0.022	Small
Jump 9 min (cm)	32.6 $\pm$ 6.3	37.2 $\pm$ 8.4	5.1 (3.9; 6.5)	0.61 (0.32; 0.9)	0.002	Moderate
<b>Peak power</b>						
Power 15 s (W)	3137 $\pm$ 646	3102 $\pm$ 575	-37 (-141; 91)	0.05 (-0.10; 0.20)	0.577	Trivial
Power 1 min (W)	3184 $\pm$ 654	3324 $\pm$ 623	139 (48; 239)	0.22 (0.05; 0.39)	0.040	Small
Power 3 min (W)	3108 $\pm$ 653	3297 $\pm$ 595	189 (92; 293)	0.44 (0.18; 0.7)	0.009	Small
Power 5 min (W)	3018 $\pm$ 514	3277 $\pm$ 566	253 (164; 334)	0.40 (0.21; 0.59)	0.002	Small

Power 7 min (W)	3037 ± 557	3208 ± 597	171 (72; 274)	0.29 (0.11; 0.47)	0.011	Small
Power 9 min (W)	3050 ± 554	3221 ± 587	172 (86; 270)	0.30 (0.13; 0.47)	0.008	Small

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4 PAP = Post-activation potentiation; SD = Standard deviations; CI = Confidence intervals; cm = centimetres; s = seconds; min = minutes; W =  
5 watt.

6

1 Table 2. Summary of Control and PAP impulse and force data (n = 18). Data are presented in mean  $\pm$  SDs.

2

<b>Variable</b>	<b>Control</b>	<b>PAP</b>	<b>Delta difference</b>	<b>Effect size</b>	<b>p-level</b>	<b>Effect size</b>
	<b>Mean <math>\pm</math> SDs</b>	<b>Mean <math>\pm</math> SDs</b>	<b>(90% CI)</b>	<b>(90% CI)</b>		<b>assessment</b>
<b>Jump impulse</b>						
Impulse 15 s (N·m)	177.5 $\pm$ 33.4	173.9 $\pm$ 39.5	-3.6 (-9.3; 2.6)	-0.10 (-0.25; 0.05)	0.263	Trivial
Impulse 1 min (N·m)	178.3 $\pm$ 39.3	182.9 $\pm$ 35.3	4.6 (0.18; 9.1)	0.13 (-0.01; 0.26)	0.105	Trivial
Impulse 3 min (N·m)	178.5 $\pm$ 34.4	182.1 $\pm$ 36.8	3.6 (-2.4; 9.6)	0.11 (-0.08; 0.3)	0.330	Trivial
Impulse 5 min (N·m)	176.6 $\pm$ 33.7	185.6 $\pm$ 37.7	9.0 (5.2; 13.4)	0.26 (0.08; 0.44)	0.021	Small
Impulse 7 min (N·m)	175.3 $\pm$ 32.4	184.9 $\pm$ 38.9	9.6 (4.3; 15.3)	0.27 (0.09; 0.45)	0.016	Small
Impulse 9 min (N·m)	175.5 $\pm$ 33.4	184.8 $\pm$ 38.2	9.3 (4.4, 14.7)	0.27 (0.07; 0.47)	0.029	Small
<b>Jump force</b>						
Force 15 s (N)	1586 $\pm$ 355	1540 $\pm$ 386	-46 (-77; -24)	-0.12 (-0.23; -0.01)	0.066	Trivial
Force 1 min (N)	1579 $\pm$ 370	1605 $\pm$ 393	25 (1; 53)	0.07 (-0.01; 0.15)	0.130	Trivial
Force 3 min (N)	1566 $\pm$ 348	1601 $\pm$ 390	34 (6; 60)	0.09 (0.01; 0.18)	0.088	Trivial
Force 5 min (N)	1530 $\pm$ 300	1615 $\pm$ 376	85 (41; 130)	0.25 (0.08; 0.42)	0.021	Small

Force 7 min (N)	1518 ± 366	1604 ± 411	85 (46; 129)	0.23 (0.11; 0.35)	0.005	Small
Force 9 min (N)	1532 ± 346	1597 ± 413	64 (28; 104)	0.18 (0.06; 0.31)	0.026	Trivial

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4 PAP = Post-activation potentiation; SD = Standard deviations; CI = Confidence intervals; cm = centimetres; s = seconds; min = minutes; N =

5 Newton.

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1 Table 3. Summary of Control and PAP Isokinetic data (n = 18). Data are presented in mean  $\pm$  SDs.

2

<b>Variable</b>	<b>Control</b>	<b>PAP</b>	<b>Delta difference</b>	<b>Effect size</b>	<b>p-level</b>	<b>Effect size</b>
	<b>Mean <math>\pm</math> SDs</b>	<b>Mean <math>\pm</math> SDs</b>	<b>(90% CI)</b>	<b>(90% CI)</b>		<b>assessment</b>
<b>Peak Torque</b>						
<b>(60°·s<sup>-1</sup>)</b>						
Quad Conc (Nm·Kg <sup>-1</sup> )	205 $\pm$ 53	212 $\pm$ 53	7.7 (4.6; 10.9)	0.13 (0.07; 0.19)	0.001	Trivial
Ham Conc (Nm·Kg <sup>-1</sup> )	124 $\pm$ 35	133 $\pm$ 37	9.6 (4.8; 14.4)	0.24 (0.12; 0.36)	0.003	Small
Ham Ecc (Nm·Kg <sup>-1</sup> )	147 $\pm$ 55	159 $\pm$ 52	12.1 (6.1; 18.1)	0.22 (0.11; 0.33)	0.003	Small
<b>Ratio</b>						
<b>(60°·s<sup>-1</sup>)</b>						
Conventional ratio	0.60 $\pm$ 0.05	0.63 $\pm$ 0.09	0.03 (0.01; 0.05)	0.6 (0.03; 1.2)	0.083	Moderate
Functional ratio	0.71 $\pm$ 0.14	0.78 $\pm$ 0.14	0.07 (0.03; 0.09)	0.21 (0.12; 0.3)	0.001	Small

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4 PAP = Post-activation potentiation; Quad = Quadriceps; Ham = Hamstring; Conc = Concentric; Ecc = Eccentric; SD = Standard deviations; CI =

5 Confidence intervals; s = seconds.

Figure 1. Experimental and control procedure

