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ORIGINAL ARTICLE

Short-term maximal performance depend on post-activation potentiation stimuli type and recovery period

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Abstract The purpose of this study was to identify the acute effects of two types of warm-up (i.e. plyometric and isometric) interventions on jump performance. Forty-five subjects volunteered to participate in our study. Participants were randomly assigned in a plyometric group ($n = 15$; age 14.79 ± 0.43; mass 57.64 ± 4.52; height 174.61 ± 5.97), isometric group ($n = 15$; age 14.80 ± 0.41; mass 57.13 ± 4.78; height 174.57 ± 5.75), and control group ($n = 15$; age 14.67 ± 0.49; mass 57.93 ± 4.09; height 175.30 ± 4.93). Pre- and post-measures (before, immediately, 5, 10, and 15 min after) for sargent jump test (SJT) and five jump test (5JT) were analyzed using a repeated measures ANOVA. There was a significant ($p < 0.01$) difference in SJT and 5JT depending on intervention types ($\eta_p^2 = 0.430$ and $\eta_p^2 = 0.467$, respectively). The results showed that both experimental groups had increases in SJT and 5JT compared to the control group. In the plyometric intervention, increases in SJT and 5JT up to 15 min after can be linked to dissipation of fatigue. Reduction of muscle function at potentiated state can be seen in the isometric scheme wherein jump performances decreased at 15 min. Post-potentiating activation has been induced using various types of exercise protocols. The optimal recovery period for recreationally trained men has not been clearly defined.

Keywords Warm-up · Potentiating activation · Jump performance · Recovery

Introduction

Muscle injury is one of the major problems faced by athletes. As a result, it is imperative to utilize the most effective means to aid in deterring these injuries [1]. It is assumed that a warm-up is intended to improve a muscle's dynamics such that it is less inclined to injury and also to prepare the athlete for the demand of exercise to improve performance. Recently, there has been an increased interest in utilizing various warm-up schemes to evoke post-activation potentiation (PAP) among individuals [2, 3]. In fact, PAP refers to enhancement of muscle twitch contraction force that has been demonstrated following brief high-intensity conditioning contractions of the same muscle [4]. Therefore, PAP serves to improve muscular performance, potentially enhancing exercise performance. PAP was assessed by changes in electrically evoked isometric muscle twitches recorded throughout both protocols. In addition, PAP is dependent on various stimuli dependent on various stimuli [5, 6]. The system develops into a potentiated state after an applied stimulus [4]. We found various stimuli types including isometrics, resistance, and plyometrics exercises [2, 7, 8], which have been used to enhance power output in further activities such as explosive contractions and sport-specific actions [9, 10]. Cilli et al. [11] showed that resistant dynamic warm-up corresponding to 6–10% of body weight may provoke PAP responses that are able to increase jump performance. Heavy-load bench press has served as

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a potentiating exercise to enhance upper-body power [12], while vertical jump and sprint performance also improved following a high-force activity [13]. Studies have shown an enhancement in jumping [3] and running performance due to PAP after resistance sets [14], although there are some studies which reported no such effects on jumping performances [15]. Plyometric exercises are commonly used to increase explosive actions in soccer players [7]. Alternatively, acute changes in muscle architecture and increased recruitment of higher order motor units have also been proposed as potential mechanisms [4]. It appears that PAP has its greatest effect during submaximal contractions in which motor units are firing at relatively low frequencies, such as the case of endurance exercise [16]. Furthermore, it could be argued that PAP might counteract the onset of fatigue [16] at the peripheral level. Additionally, a submaximal fatigue is defined as the balance between fatigue-induced impairments and neuromuscular strategies to sustain performance [17].

Despite the potential benefits associated with PAP, many studies reported no significant performance improvements [8]. These conflicting results clearly indicate that the recovery time influences the PAP responses and warrant further research to clarify these differences [5]. In fact, for an optimal PAP response, some stimulation variables should be considered [6]. Researchers suggested that a short (5 min) [18], moderate (8–12 min) [9], and high (18.5 min) [15] recovery period have led to optimize the response to a high-intensity stimulus. There is an optimal interval between stimulation and assessment, which varies depending on the intensity and type of the stimulus [19]. The literature regarding an athlete's ability to harness PAP has been conflicting and can in part be explained by numerous potential methodological differences in the various studies [20]. It is known that increasing muscle force induced by PAP dissipates after approximately 30 min and fatigue overcomes the PAP after 1 min of the stimulus [21]. Hence, we can assume that following proper recovery is a key parameter for the benefit of the PAP phenomenon. Despite the potential of reactive movements as a stimulus to induce PAP, the literature is lacking in data about comparisons between various types of movements as a conditioning contraction stimulus. Indeed, to the best of our knowledge, there are several studies that although unsuccessful to determine an optimal PAP time for all individuals, have analyzed this issue. To our knowledge, this is the first study designed to identify the optimal recovery time depending on different types of exercise protocols (i.e., plyometric and isometric stimuli) to elicit potentiation. In addition, it would be interesting to examine the effectiveness of the PAP in vertical and horizontal jump performance, due to no studies having these issues. In fact, soccer is an intermittent sport, which requires different physiological components including aerobic and anaerobic power, which are both important features [22, 23]. The capacity to produce varied powerful actions during a 90-min game is associated with high aerobic capacity [24]. However, the ability to produce an explosive single-bout effort is as important as aerobic power for success in soccer [25]. Therefore, sprint running performance, with or without the ball, is an important factor that may explain the superiority of a winning team. Similarly, jumping performance might be considered as determinant of physical demands during soccer match [26]. Furthermore, Arnason et al. [27] showed that vertical jump performance was related to team success in semiprofessional soccer players. Recent studies have proposed the 5-jump test (5JT) for distance as a practical alternative to estimate lower limb explosive power of selected population of athletes including soccer players [28]. Thus, we aimed to study using a methodology designed to identify and compare the optimal recovery time to elicit potentiation after performing two protocols differentiated by the type of exercise (i.e., plyometric and isometric stimuli) on jumping performance in young soccer players. We hypothesized that both isometric and plyometric exercises would induce PAP in lower limb and positively affect the performance of subsequent jumps. Furthermore, we hypothesized that a longer period of recovery could increase the jumping performance by reducing the fatigue effects.

Methods

Participants

Forty-five healthy men [age 14.75 ± 0.44 year; body mass 57.88 ± 4.45 kg; height 174.97 ± 5.13 cm; body mass index (BMI) 18.91 ± 1.26 kg m^{-2}; body fat (BF) 7.48 ± 0.88%] volunteered to participate in the present study (Table 1). A medical examination was carried out before the start of the study. All participants were members of a second division Tunisian soccer club. All subjects had previous experience in team soccer of at least 6 years and had trained for approximately 2 h/day, 4–5 days/week (including every official match played) during the four previous years. Participants were randomly assigned into a plyometric exercises group (PG), isometric exercises group (IG), or a control group (CG). Prior to experimentation, a written informed consent was obtained from the subjects. All participants were asked to maintain their usual physical activity level, diet, and sleeping habits for the duration of the study. None of the subjects reported any current injuries of the spine or the lower extremities.

The study was carried out in accordance with the guidelines contained in the Declaration of Helsinki and was approved by the Ethical Committee on Human Research (ECHR) of the University of Sfax.

Table 1 Anthropometric measurements of the two groups (one-factor ANOVA)

	Age (years)	Body mass (kg)	Height (cm)	BMI (kg/m^2)	BF (%)
PG	14.8 ± 0.4	57.6 ± 4.5	174.6 ± 5.9	18.7 ± 1.1	7.2 ± 0.8
IG	14.8 ± 0.4	57.1 ± 4.8	174.6 ± 5.7	18.7 ± 1.1	7.4 ± 0.9
CG	14.7 ± 0.5	57.9 ± 4.1	175.3 ± 4.9	18.9 ± 1.4	7.5 ± 0.9
Statistics *p*	> 0.05	> 0.05	> 0.05	> 0.05	> 0.05

Mean ± SD

BMI Body mass index, *BF* Body fat, *PG* experimental group using plyometric exercises, *IG* experimental group using isometric exercises, *CG* control group

Testing procedures

This study was administered at an outdoor facility at 6:00 pm for four sessions. The first session was devoted to anthropometric measurements and familiarization. Body mass was measured to the nearest 0.1 kg with a digital scale (Ohaus, Florham Park, NJ). Height was measured with a standing stadiometer and recorded with a precision of 1 mm. Subjects' body fat percentage was calculated using six skin-fold measurements (triceps, subscapularis, suprailiac, abdominal, thigh, and calf).

Session two took place after 7 days. During the second session, subjects performed a standardized warm-up consisting of a 10 min of light jogging and coordination movements [29]. This was succeeded by dynamic exercises which include leg lunges (1 × 4/leg), leg swing (1 × 4/leg), bilateral squat (1 × 4), bilateral heel raises (1 × 4), and 6 hops to 5 m sprint (1 × 3). A 3-min rest was provided after the warm-up. Next, the subjects performed isometric, plyometric, or a control intervention. For isometric exercise, the subjects executed a wall-squat (4 × 10 s) wherein the subjects were asked to lean against the wall with knees bent at approximately 90°. Rest interval in between sets was 1 min. After, the subject maintained this position (sit wall) for 10 s (1 × 4). Finally, participant remained in a squat position for 10 s (1 × 4). Plyometric exercises involved six hurdle jumps for (1 × 4), squat jump to the front (1 × 4), and bilateral side to side hops on one leg (1 × 4). Rest interval between hop exercises was set at 1 min. All isometric and plyometric exercises are presented in Table 2.

The CG did not perform any exercise after the warm-up. The CG performed their tests immediately after warm-up with the same delay than PAP groups (Fig. 1).

Immediately after each intervention, the subjects' sargent jump test (SJT) and five jump test (5JT) were measured. Tests were performed after 5, 10, and 15 min of passive recovery. Recovery durations were presented in a random order.

For SJT, subjects were asked to stand by a wall and extend their right arm with feet flat on the floor. The highest point was marked as baseline (M1). After M1, the subjects were requested to perform a countermovement vertical jump and mark the highest height (M2). Difference of M2–M1 was recorded as the vertical jump. Subjects performed three trials with rest interval of 1 min in between trials for SJT. In the 5JT, subjects executed four alternating leg bounds followed by a bilateral landing. The distance from the starting position and the landing area was measured for each 5JT trial. Three trials for 5JT were administered with rest interval of 1 min in between trials. The best trial in SJT and 5JT were kept for analyses.

Statistical analysis

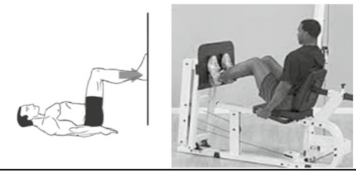
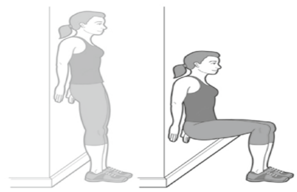
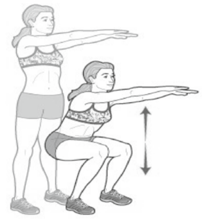
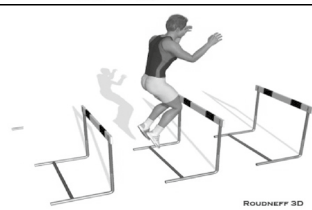
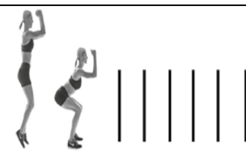
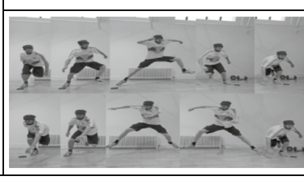
Data are displayed as mean, and standard deviation. The Shapiro–Wilk *W* test of normality revealed that the data were normally distributed. Once the assumption of normality was confirmed, parametric tests were performed. Two-way repeated measures ANOVA was employed to determine the main effects of intervention and time. Similarly, the same method was used to identify the interaction of intervention and time. Effect size was estimated using partial eta squared (η_p^2). Subsequent one-way repeated measures ANOVA with Bonferonni post hoc was administered for any significant interaction in SJT and 5JT. Statistical significance was set at 0.05 level alpha.

Results

Means, standard deviations of group performance of SJT and 5JT can be seen in Table 3.

For SJT performance, there was a significant main effect for intervention at $F(2, 28) = 10.6$, $p < 0.01$, $\eta_p^2 = 0.430$. Similarly, there was a significant main effect for time, $F(3, 42) = 79.4$, $p < 0.01$, $\eta_p^2 = 0.850$. There was a significant interaction between intervention and time at $F(6, 84) = 31.4$, $p < 0.01$, $\eta_p^2 = 0.692$. Bonferonni post hoc showed that PG and IG displayed greater SJT than CG after 10 min ($p = 0.009$; $p = 0.000$, respectively) and after 15 min ($p = 0.000$; $p = 0.003$; respectively). There was no significant difference between IG and PG at 5 or 10 or at 15 min of recovery. In fact, main effect for time in SJT showed that the PG exhibited a significant difference in SJT across

Table 2 Different type of postactivation potentiation stimuli exercises

Isometreic		Is an isometric contraction of quadriceps against the wall and push it with as maximal as possible. In order to replace the same ex. with the leg press machine. Keep up this position for 10 s
		The subject should keep up this position (sit wall). Subject should keep up in squat position for 10 s
		Demi-Squat Position Subject should keep up in squat position for 10 s
Plyometric		Forward Hurdle Hops 4 hurdle jumps at 50 cm and 2 hurdle jumps at 70 cm
		Forward Squat Jump until the cone
		Jump on one leg once right once left until the cone

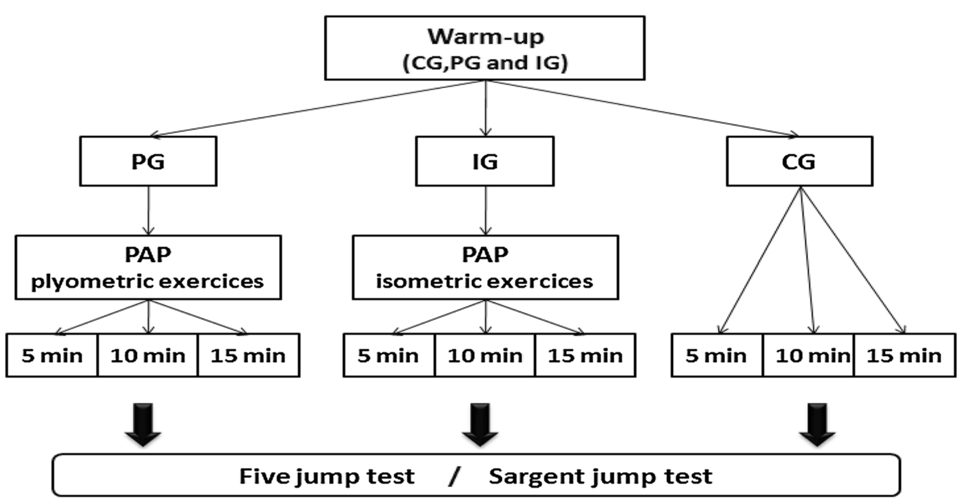


Fig. 1 Experimental design. *PG* experimental group using plyometric exercises, *IG* experimental group using isometric exercises, *CG* control group, *pre* before PAP exercises, *5 min* after 5 min of rest, *10 min* after 10 min of rest, *15 min* after 15 min of rest

time at $F(3, 42) = 49.2$, $p < 0.01$. Results showed that SJT measured at pre-test was significantly lower than SJT performance after 5 min ($p = 0.004$), 10 min ($p = 0.000$), and 15 min ($p = 0.000$) of the plyometric intervention. Regardless of recovery period, our plyometric intervention led to SJT improvements. Besides, even the time of recovery and even the performance in PG were more important. We observed that 5th min performance was significantly lower than 10th ($p = 0.002$) and 15th min ($p = 0.000$) SJT. At 10th min, SJT was also significantly ($p = 0.000$) lower than 15th min of recovery following the plyometric stimulus. Concerning the IG, SJT difference across time was also seen, $F(3, 42) = 50.6$, $p < 0.01$. Pre-test SJT was significantly lower than SJT at 5th ($p = 0.000$), 10th ($p = 0.000$), and 15th min ($p = 0.000$). SJT at 5 min was lower after 10 min ($p = 0.001$). 15th min SJT was significantly ($p = 0.000$) higher than rest values. However, no significant SJT difference was found after 15 min compared to 10 and 5 min. In contrast, the CG displayed a significant difference in SJT across time, $F(3, 42) = 3.60$, $p < 0.05$. Figure 2 depicts the SJT performance of groups across time.

For the 5JT, there was a significant main effect for intervention at $F(2, 28) = 55.8$, $p < 0.01$, $\eta_p^2 = 0.799$. Main effect for time was also found out to be significant, $F(3, 42) = 66.5$, $p < 0.01$, $\eta_p^2 = 0.826$. There was a significant main interaction between intervention and time, $F(6, 84) = 12.2$, $p < 0.01$, $\eta_p^2 = 0.467$. In the main effect of intervention, pre 5JT across groups were found with no significant difference at $F(2, 28) = 3.30$, $p > 0.05$. At 5th min, 5JT was seen to be significantly different between groups, $F(2, 28) = 18.0$, $p < 0.01$, $\eta_p^2 = 0.562$. The CG showed a lower 5JT when compared to the PG ($p = 0.000$) and IG ($p = 0.004$). A similar trend in 5JT difference at 10 min was identified between interventions (i.e., isometric and plyometric), $F(2, 28) = 33.8$, $p < 0.01$, $\eta_p^2 = 0.707$.

We determined that the control condition was lower than PG ($p = 0.000$) and IG ($p = 0.000$). In the main effect for time, it was observed that PG exhibited a significant difference in 5JT across time, $F(3, 42) = 46.7$, $p < 0.01$. Pre 5JT was lower than 5th ($p = 0.004$), 10th ($p = 0.000$), and 15th min 5JT ($p = 0.000$). 5JT performed at 15 min were greater than those measured at 5th min ($p = 0.000$) and 10th ($p = 0.023$) 5JT values. For the IG, a significant difference was also found out across time, $F(3, 42) = 16.7$, $p < 0.01$. Pre-5JT values were lower than 5th min ($p = 0.002$), 10th min ($p = 0.000$), and 15th min ($p = 0.000$) of recovery. Moreover, results showed a significant increase in 5JT performance in PG compared to IG only after 15 min of recovery. 10th min and 15th min 5JT was non-significantly different. Lastly, performance in PG and IG were significantly ($p = 0.000$) higher than CG (Fig. 3).

Discussion

The purpose of our study was to identify the effects of two warm-up conditions on SJT and 5JT performances and to identify the best recovery period for each of them. This is the first study that examined the effects of multi types of PAP protocols on jumping performance in young male soccer players. The main finding of this study was the significant superior effect of both PAP exercise compared to the control conditions. It was assumed that exercise without load could be an efficient method to cause substantial PAP effects. This type of exercise used in our study is easier to be used anywhere with a minimum of materials. We showed that plyometric effect remained efficient even after 15 min of rest. In

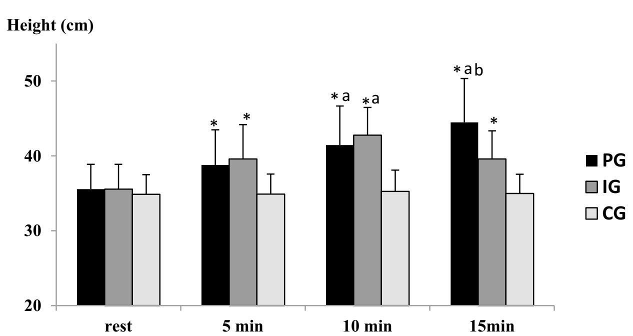


Fig. 2 Sargent jump test performances measured during rest, after 5–10–15 min of recovery for the tree groups (CG, PG and IG). *PG* experimental group using plyometric exercises, *IG* experimental group using isometric exercises, *CG* control group, *pre* before PAP exercises, *5 min* after 5 min of rest, *10 min* after 10 min of rest, *15 min* after 15 min of rest. *Significant difference compared to rest values, $p < 0.05$. [a]Significant difference compared to 5 min, $p < 0.05$. [b]Significant difference compared to 10 min, $p < 0.05$

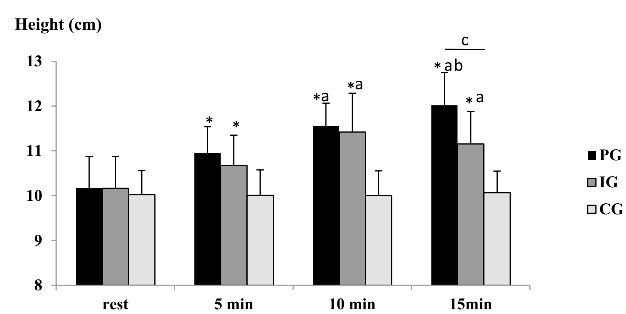


Fig. 3 Five jump test performances measured during rest, after 5–10–15 min of recovery for the tree groups (CG, PG and IG). *PG* experimental group using plyometric exercises, *IG* experimental group using isometric exercises, *CG* control group, pre before PAP exercises, *5 min* after 5 min of rest, *10 min* after 10 min of rest, *15 min*: after 15 min of rest. *Significant difference compared to rest values, $p < 0.05$. [a]Significant difference compared to 5 min, $p < 0.05$. [b]Significant difference compared to 10 min, $p < 0.05$. [c]Significant difference between PG and IG, $p < 0.05$

fact, the best performances were recorded at 15th min following the PAP. Therefore, isometric intervention decreased after 15 min of recovery. The best performances were shown at 10th min of rest. The fact that these performance gains were much higher than in studies using isometric conditioning contractions suggests the importance of matching the type of the conditioning contractions and the type of the subsequent activity where performance is to be increased.

Results showed that PAP was assessed by changes in electrically evoked isometric muscle twitches recorded throughout both protocols. In fact, PG and IG recorded higher values SJT and 5JT performances than CG. We suggest that these increases were due to the different mechanisms in response to isometric versus plyometric exercise. Indeed, it has been shown that PAP induces an increase in blood flow to the tissues and an increase in the speed of muscular contraction and nerve transmission [1]. Although, increasing muscle temperature may in turn reduce reaction time. In fact, our findings are similar to previous studies that showed an improvement in lower body performances. Performance enhancement coincided with previous studies which were attributed to PAP [14, 30]. Moreover, Smilios et al. [31] reported an increase in jumping performance between the resistance sets during a training session. Bergmann et al. [30] showed that a bout of ten maximal reactive hops caused a substantial PAP manifested as an increase in drop jump. This assumption is confirmed by our finding because the PAP effect was observed only during the 5th min after the last set, and indicating possible effects of resistance sets is an important requirement for the presence of PAP [14]. PAP effects after an electrically induced contraction appear immediately after the proceeded contraction [32] but it does not always occur in ballistic movements at the end of the resistance training session, perhaps due to the fatigue effect. In other studies, an enhancement in jumping performance was observed immediately after a set of maximum isometric contractions [26] or after a set of high-intensity dynamic exercises [33]. Khamoui et al. [34] found that jump height significantly increased (2.8%) following the potentiating exercise. Likewise, Thompsen et al. [35] observed that the resistance dynamic warm-up caused 5.3 and 5.4% improvement in long jump and vertical jump performance, respectively. It has been reported that a resistance corresponding to 2% of body weight increased vertical jump performance by 10.1%, and a resistance corresponding to 6% of body weight increased vertical jump performance by 13.5% and long jump performance by 12.5% [36]. Nevertheless, no PAP effect on running speed was observed in junior basketball players who did not follow systematic resistance and/or power training [37]. Moreover, Jo et al. [5] showed there was no significant difference in performance among control and experimental trials. The authors suggested that heavy-load squats fail to induce PAP (Fig. 4).

Another variable in this study was the rest interval after the PAP protocol for SJT and 5JT sessions. Results demonstrated that optimal rest interval was dependent on mechanical loading. For example, PG performance ranged from 5 to 10 min while IG caused a decline in SJT after 10 min. In the plyometric intervention, increasing SJT and 5JT up to 15 min can be linked to dissipation of fatigue. However, a reduction of muscle performance at a potentiated state can be seen in the isometric session wherein jump performance

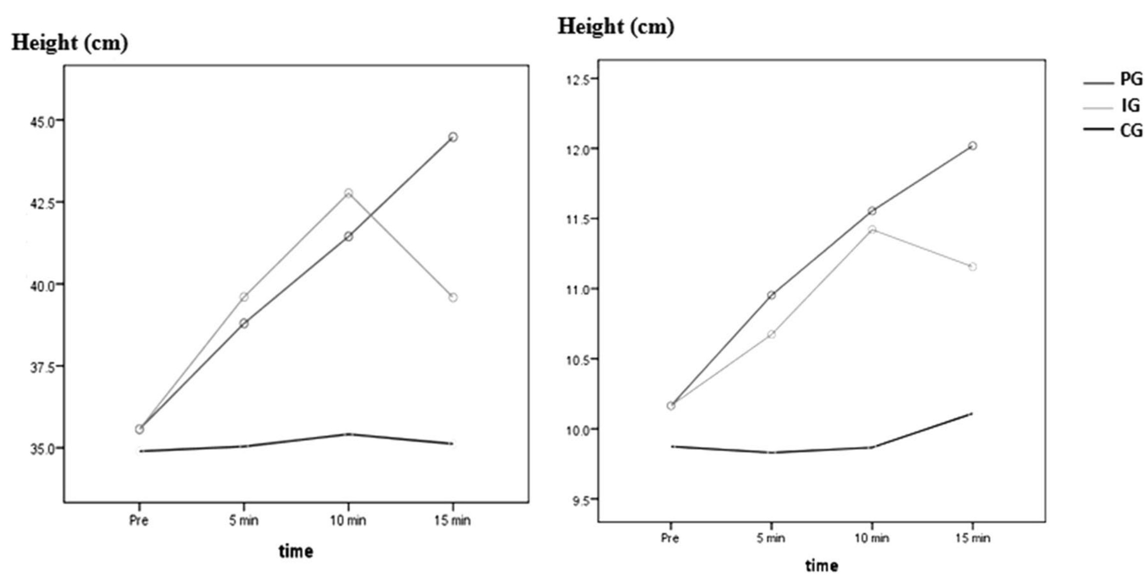


Fig. 4 SJT and 5JT performances gait at rest, after 5–10–15 min of recovery for the three groups. *PG* experimental group using plyometric exercises, *IG* experimental group using isometric exercises, *CG* control group, *pre* before PAP exercises, *5 min* after 5 min of rest, *10 min* after 10 min of rest, *15 min* after 15 min of rest

decreased at 15th min of rest. In fact, the relationship between musculotendinous stiffness and muscle fiber type was considered [38]. Recovery intervals influence the effect of the fatigue which has been previously evaluated with metabolic and neural parameters [39]. These findings suggest that time-dependent performance enhancement from PAP may be affected by mechanical loading. Rassier and Macintosh [40] showed that fatigue and PAP could coexist after heavy resistance exercise and that performance improves only when PAP exceeds fatigue. Advanced weightlifters also develop fatigue resistance to heavier loads as a training adaptation; thus, allowing PAP to predominate immediately after resistance exercise [15]. Subjects might potentiate with less rest after the stimulus (5–10 min), whereas weaker subjects may require longer rest durations (15–20 min) [5].

Kilduff et al. [9] examined the variations of the peak power output during countermovement jumps immediately (within 15 s) 4, 8, 12, 16, and 20 min after three repetition maximum back squats in professional rugby players. They found that peak power output increased following 8 and 12 min of rest, suggesting 8–12 min to provide optimal recovery following a heavy-load back squat in professional rugby players. Similarly, Kilduff et al. [41] examined peak countermovement jump height immediately (within 15 s), 4, 8, 12, 16, 20, and 24 min after heavy-load back squat and found that peak jump height occurred 8 min post intervention, indicating this rest period to be optimal. Both Kilduff's studies seem to demonstrate at least 8 min of rest after a heavy-load back squat intervention to be optimal for enhanced countermovement jump performance in professional rugby players. Other previous investigations using female and male athletes, reported that CMJ performance decreased (< 30 s) followed by a significant improvement 4 min after performing PAP exercise [42]. Kilduff et al. [9] found significant decreases in CMJ performance after (15 s) alongside an increase of CMJ power output displayed from 8 to 12 min after performing a 3-RM squat [43]. However, authors reported more consistently better PAP response occurred between 8 and 12 min in more than 80% of participants [44]. Batista et al. [45] showed various variability of CMJ performance in response to 5 s maximal isometric leg press contraction and in response to three rep of 5 s of maximal isometric leg press contraction in physically active individuals with similar muscle strength. Indeed, moderate- and high-volume protocols seem to be more effective to elicit potentiation with respect to the low volume, at least at some points within the 12-min period [45].

Indeed, the study is limited to an acute finding using SJT and 5JT performance only. Future studies should warrant the use of other performance measures in longer time settings. In addition, the experimental protocols failed to quantify physiological measures (e.g., heart rate, temperature) which may be helpful. Therefore, we suggest researchers and practitioners consider potential PAP effects on isometric and plyometric strength assessment protocols. It will be interesting to examine motoneuronal output as a likely mechanism responsible for PAP-induced performance gains. It is clear that further investigation is warranted concerning acute muscle architecture changes and how those changes affect PAP.

Conclusion

In summary, isometric and plyometric schemes produced significantly greater SJT and 5JT than a control up to 15 min in PG even after 15 min. Although the IG showed similar improvements; however, 5JT and SJT decreased after 15 min. It seems that fatigue or dissipation of PAP induced a decrease in performance across time. Hence, PAP has been induced using various types of exercise protocols. The optimal recovery period for recreationally trained men have not been clearly defined, and it may be feasible that recovery requirement differs as a function of type of stimuli. Future studies should focus on examining the effects of PAP on soccer female population, to better understand whether gender has an effect on anaerobic performances.

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Compliance with ethical standards

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Conflict of interest The authors declare that there is no conflict of interests regarding the publication of this paper.

Informed consent Informed consent was obtained from all individual participants included in the study.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

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