

Research article

Influence of type of muscle contraction and gender on postactivation potentiation of upper and lower limb explosive performance in elite fencers

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Abstract

The purpose of this study was to evaluate the postactivation potentiation (PAP) effect of isometric and plyometric contractions on explosive performance of the upper and the lower limbs in male and female elite athletes. Thirteen male and ten female international level fencers performed four protocols of either isometric (3 sets of 3 sec) or plyometric (3 sets of 5 repetitions) bench and leg press, in a within subject randomized design. Before and immediately after the PAP treatment and following 4, 8, 12 min, explosive performance was measured by performing a countermovement jump (CMJ) or a bench press throw. Statistical analysis revealed significant time effect for peak leg power during the CMJ ($p < 0.001$) only for men, with values after the isometric PAP treatment being lower than baseline at the 8 and 12 min time points (by 7.5% (CI95% = 3.9-11.2%) and 8.7% (CI95% = 6.0-11.5%, respectively), while after the plyometric PAP treatment peak leg power remained unchanged. A significant negative correlation was found between leg strength (as expressed by 1-RM leg press performance) and the change in peak leg power between baseline and after 12 min of recovery only in male fencers ($r = -0.55$, $p < 0.05$), suggesting that stronger individuals may show a greater decrease in peak leg power. Based on the above results we conclude that lower body power performance in international level fencers may be negatively affected after isometric contractions and thus they should be advised against using isometric exercises to induce PAP with the protocol prescribed in the present study. Furthermore, gender and strength level must be considered in the practical application of PAP.

Key words: Warm-up, vertical jump, bench-press, fatigue, isometric, plyometric.

Introduction

Fencing is characterized by short, frequent bouts of high intensity exercises, spaced by low intensity activity and recovery periods. Fencers in a typical fencing competition are forced to follow repeated accurate defensive and offensive kinetic patterns, often requiring high muscle strength and power (Barth and Beck, 2007). The importance of strength and power and their potential association to the functional fencing performance has been recently investigated (Tsolakis et al., 2010). The results of that study indicated that concentric explosive strength and fast stretch-shortening cycles of the leg muscles are important in maximizing leg functional power characteristics in elite fencers.

Given the major role of muscle power and explosiveness of muscular actions in improving performance, several studies have examined the effectiveness of various training methods proposed to enhance power (Kraemer

and Newton, 2000; Newton and Kraemer, 1994). Postactivation potentiation (PAP) is a common technique used for inducing a short-term increase in force and power output during training and competition (Hodgson et al., 2005; Robbins, 2005). PAP is the phenomenon where previous intense muscle contractions increase subsequent force and power output over the baseline level (Sale, 2002). The mechanisms that cause PAP have been proposed to be related with metabolic changes within the muscle (i.e. myosin light chain phosphorylation; Grange et al., 1993) as well as with an alteration in α -motoneuron excitability as reflected by changes in the H-reflex (Miszczek, 2003; Zucker and Regehr, 2002.)

Dynamic (Chatzopoulos et al., 2007; Kilduff et al., 2007), isometric (French et al., 2003; Gosen and Sale, 2000; Hamada et al., 2000) and ballistic or plyometric (Hilficker et al., 2007; Masamoto et al., 2003; Till and Cooke, 2009) contractions at maximal or sub-maximal levels have been used as potentiating exercises to enhance upper and lower body performance in various tasks. However, it is not certain which type of contraction causes the greatest PAP effect.

Among the number of factors that may potentially influence the magnitude of PAP, the effect of gender has received limited attention (Rixon et al., 2007; Witmer et al., 2010). Moreover, there have been very few applied studies comparing different methods of eliciting PAP in competitive (or elite) athletic populations (Rixon et al., 2007; Till and Cooke, 2009). Studying highly trained individuals may provide further evidence regarding the effectiveness of different types of exercise used to attain PAP, due to the possibly greater PAP response of athletes compared to weaker or untrained individuals (Hamada et al., 2000; Rixon et al., 2007; Terzis et al., 2009; Witmer et al., 2010)

Therefore, the primary goal of this study was to examine the effect of isometric and plyometric contractions on explosive performance of the upper and the lower limbs as measured by the bench press throw and countermovement jump (CMJ), and to compare their effectiveness in male and female elite level fencers. It was hypothesized that men and in general the stronger participants would have a greater PAP effect compared to women and the weaker participants. A secondary goal was to determine the optimal time between PAP intervention and the subsequent explosive activity.

Methods

Participants

The sample consisted of 23 (13 males and 10 females) international level fencers. All athletes were members of the Greek National team, having considerable experience of international competitions. The physical characteristics of the subjects are shown in Table 1. All subjects had at least one year of resistance training experience and were familiar with bench and leg press as part of their regular training sessions. Prior to data collection, informed consent was obtained from each subject, after a thorough description of the risks being involved. The study was approved by the local Institutional Review Board and all procedures were in accordance with the Helsinki declaration of 1975, as revised in 1996. This study conducted during the last two weeks of a 4-week off-season training camp, in which fencers engaged with recreational team games (volleyball, football, basketball).

Table 1. Descriptive characteristics and maximal strength (1-repetition maximum; 1-RM) of the subjects. Data are means (\pm SD).

	Males (n=13)	Females (n=10)
Age (y)	21.8 (3.7)	22.7 (4.8)
Height (m)	1.79 (.05)	1.69 (.07) **
Weight (kg)	76.1 (7.8)	60.9 (4.6) **
Body fat (%)	13.5 (4.4)	21.5 (4.6) **
1-RM Leg press (kg)	219 (44)	118 (29) **
1-RM Bench press (kg)	77 (8)	38 (5) **

** $p < 0.01$ compared with males

Experimental design and procedures

This study was designed to investigate the effect of PAP on upper and lower body explosive performance in international level fencers of both genders. More specifically, a repeated measure, within subject randomized design, involved 2 treatments (isometric and plyometric exercises) was used to evaluate the compare the effects of PAP on bench throw and jumping performance. Moreover, in order to evaluate the fatigue and PAP interactions on upper and lower power output the performance tests were executed immediately following the interventions and were repeated every 4 min up to 12 min (Behm et al., 2004; Kilduff et al., 2007).

Each subject was required to attend the laboratory on at least five occasions separated by 48 hours rest over a 2 week period. During the first training session (familiarization session), stature, body mass and skinfolds were measured and the subjects were familiarized with the study procedures by performing a series of countermovement jumps and ballistic bench throws with 2-3 min recovery. In addition the subjects' one-repetition maximum (1-RM) was determined for the bench press and leg press, using a standard Smith machine and a 45° leg press machine, respectively. The two tests were separated by 30 min of rest. The protocol used in both tests was that outlined by Baechle et al. (2000) and the 1-RM was defined as the maximum resistance that could be lifted once using the proper technique. For the leg press, the subjects took the pressing position with their knees flexed at 90°. Knee angle was evaluated with a goniometer and the seat was adjusted accordingly. A standardized general warm-up consisting of 5 min light jogging and stretching was per-

formed before each test. All testing procedures were supervised and assessed according to the American College of Sports Medicine guidelines (2000).

During each experimental day (visits 2, 3, 4 and 5) and prior to the baseline performance measurements (countermovement jump or bench press throw) the subjects underwent a standardized warm-up consisting of 5 minutes of light jogging, followed by light static stretching, held for 15 sec, of the upper (biceps, triceps, deltoid and pectoralis major) or lower (quadriceps, hamstrings, gastrocnemius and gluteus) limbs musculature similar to what they do before a competition. After the warm-up two specific warm-up sets of 10 repetitions at 50% 1-RM and 5 repetitions at 75% 1-RM were performed. A 3 min rest between sets was used (Hanson et al., 2007). Then, the subjects completed either three CMJ's or three bench press (BP) throws to obtain the baseline values with 60 sec between efforts [ICC = 0.983 $p < 0.001$ and coefficient of variation (CV) = 2.7% for CMJ and ICC = 0.994, $p < 0.001$ and CV = 2.0% for BP]. Before the PAP interventions (isometric or plyometric in randomized order), subjects undertook a 3 min of seated recovery period. Then, immediately after the PAP treatment (within 15 sec) and every 4 min up to 12 min (4, 8 and 12 min), the performance tests were repeated. This time interval (4-min) was chosen because it represents approximately the pause between two consecutive matches in the pool fencing competitions (www.fie.ch/fencing/rules.aspx).

Upper body power performance before and after the PAP treatment was assessed during ballistic bench press throws using a Smith machine against a load of 40% of the individual 1-RM (Kilduff et al., 2007). During each bench press throw the subjects were instructed to throw the bar explosively and forcefully as high as possible from a starting position on their chest (Cronin et al., 2003; Newton et al., 1996). The ICC for this test was (0.993, $p < 0.001$). The placement of the hands was recorded and was kept constant in all sessions (Murphy et al., 1995). The construction of the machine allowed a safe immobilization of the barbell, protecting the body of subjects from any possible impact. A rotary cable extension potentiometer (Ergotest Technology, A.S. Langensud, Norway) that has been previously used (Baker, 2003; Wilson et al., 1993), was attached to the end of the bar to obtain displacement in relation with time. The results were fed into a microcomputer and linear velocity and power output were calculated.

For the measurement of lower-body performance subjects performed a countermovement jump (CMJ) with the hands on the hips and the elbows bowed outward. Peak leg power output during jumping was calculated using the equation of Sayers et al. (1999) from jump height measured with an Ergojump contact platform (Ergojump, Psion XP, MA.GI.CA., Rome, Italy) as described by Bosco et al. (1983). All participants were instructed to leave the mat with the knees and ankles extended and land in an upright position. The ICC for the peak power output during the CMJ tests was 0.98 ($p < 0.001$).

Lower body postactivation potentiation activities

The plyometric PAP activity for the lower body was the tuck jump. Subjects performed 3 sets of 5 maximal repetitions of the double legged tuck jump exercise with 60 sec rest between each effort. This plyometric drill results in high muscle fiber recruitment (Masamoto et al., 2003; Till and Cooke, 2009) and fencers empirically use as a part of warm-up activities just before competition to enhance their performance.

The isometric PAP activity for the lower body was the maximal isometric leg press. An 8-mm linked chain was attached to the 45o leg press allowing full immobilization of the subject in the desired position (90o knee flexion), which was measured by a goniometer. The three maximal isometric PAP trials against the immovable leg press machine lasted 3 sec each and were separated by 15 sec rest periods (French et al., 2003; Till and Cooke, 2009).

Upper body Postactivation potentiation activities

The plyometric PAP activity for the upper body was the clapping push-ups. This is a simple exercise that fencers use as a part of strength training workouts (Barth and Beck, 2007). From a modified push-up position with the knees in contact with the ground, subjects performed 3 sets of 5 explosive push-ups at maximal intensity, with 60 sec rest between each effort, attempting to push the body off the ground and clapping their hands before returning to the starting position (Faigenbaum et al., 2006).

The static bench press was used as the isometric PAP activity for the upper body. Maximal isometric bench press was performed by fixing the bar of a Smith press machine with an 8-mm chain at the appropriate height. With the subject in the supine position and with head, shoulder blades and buttocks in contact with the bench, the bar was adjusted so that the elbow joint was fixed at 90o (Murphy et al., 1995). The angle was measured by a goniometer. Subjects performed three maximal isometric contractions against the immovable bar of the bench press machine lasting 3 sec each and separated by 15 sec rest periods.

Statistical analyses

All statistical analyses were performed using the SPSS for Windows version 16.0 (SPCC Inc., Chicago, IL). Data were presented as means and standard deviations. A 3-way repeated measures ANOVA (type of muscle contraction, gender and time) was used to examine possible differences in power output during CMJ and bench press tests (immediately after and at 4, 8 and 12 min) between the two genders. Moreover, 2-way repeated measures ANOVA (type of muscle contraction x time) were used to compare changes in performance after the two PAP interventions in males and females, separately. A Tukey post-hoc test was performed whenever appropriate ($p < 0.05$) to locate differences between means. Bivariate correlations (Pearson) were used to examine the relationship between upper and lower body strength and changes in explosive performance after PAP. Effect size for main effects and interaction was estimated by calculating partial eta squared (η^2) values using the SPSS v.16 statistical package. Effect size for pairwise comparisons was obtained by calculating Cohen's *d*. Effect sizes were classi-

fied as small (0.2), medium (0.5), and large (0.8). Statistical significance was accepted at $p < 0.05$. Confidence intervals at the 95% level (CI95%) are presented where appropriate.

Results

Lower body performance

The 3-way ANOVA, revealed significant main effects for time ($F = 9.2$, $p < 0.000$, $\eta^2 = 0.31$) and gender ($F = 34.7$, $p < 0.000$, $\eta^2 = 0.62$), as well as a significant time x sex interaction ($F = 2.51$, $p < 0.05$, $\eta^2 = 0.11$), indicating that men performed better than women and that peak leg power output was decreased over time. Further analysis with a 2-way ANOVA showed a time x type interaction ($F = 2.42$, $p < 0.05$, $\eta^2 = 0.14$) and post-hoc analyses located a significant decrease ($p < 0.01$) in peak leg power after 8 and 12 min of recovery only in men performing the isometric protocol (Figure 1). The magnitude of this decrease was 7.5% (CI95%=3.9-11.2%) and 8.7% (CI95%=6.0-11.5%). The corresponding effect sizes (Cohen's *d*) for these differences were 0.53 and 0.65, respectively.

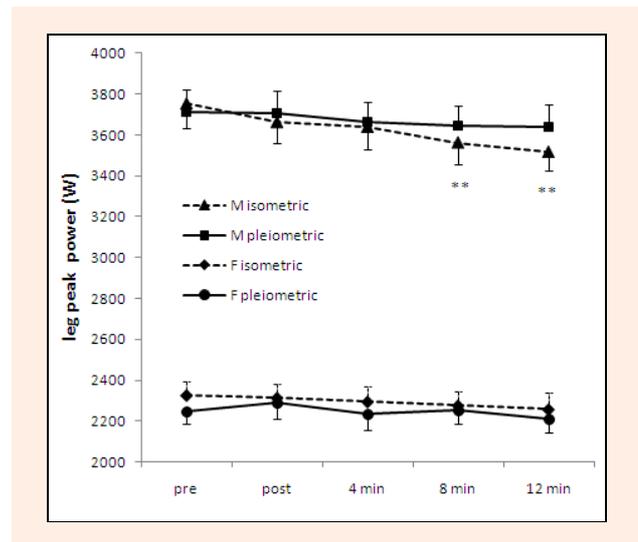


Figure 1. Leg peak power during a countermovement jump before (pre), immediately after (post) and following 4, 8 and 12 min of recovery after the upper body PAP isometric and plyometric interventions for males (M isometric and M pleiometric) and females (F isometric and F plyometric). ** $p < 0.01$ from the baseline value (pre) in the isometric trial for males (M isometric).

A significant negative correlation was found between leg strength (as expressed by 1-RM leg press performance) and the change in peak leg power output between baseline and after 12 min of recovery in the isometric condition only in male fencers ($r = -0.55$, $p < 0.05$), suggesting that stronger individuals may have a greater decrease in peak leg power.

Upper body performance

The 3-way ANOVA, revealed only a significant main effect for gender ($F = 140.6$, $p < 0.000$, $\eta^2 = 0.87$), with men performing significantly better than women in the bench press throw test, with performance remaining the same over time (Figure 2).

Discussion

This study was primarily designed to evaluate whether upper and lower-body explosive performance of international male and female fencers was enhanced after two different forms of either isometric or ballistic potentiating exercises, minimizing fatigue effects. A secondary goal was to determine a time recovery period and its effects on the potentiating PAP response.

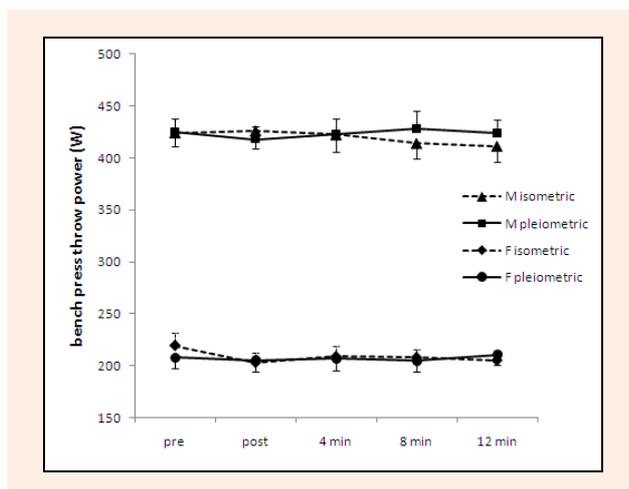


Figure 2. Bench press power before (pre), immediately after (post) and following 4, 8 and 12 min of recovery after the upper body PAP isometric and plyometric interventions for males (M isometric and M pleiometric) and females (F isometric and F pleiometric).

The main finding of the present study was that peak leg power output was decreased, instead of increased, after the isometric PAP protocol only in the male fencers, with no change in performance in the female fencers. It is important to note that males were almost twice as strong compared with females, and thus it may be argued that the stronger subjects may demonstrate a decrease in leg power following this isometric PAP protocol. This is also supported by the significant negative correlation between leg press strength and the drop in peak leg power output that was found only for the male fencers. On the other hand, upper body performance was unaffected by both PAP protocols in both genders.

The results of the current study suggest that the potentiating exercise consisting of 3 sets of 3 sec isometric leg press with 15 sec rest in between, not only failed to augment but actually reduced peak leg power and thus, the balance between the potentiating exercises and the fatigue seems to favour the later. Thus, a relatively short maximal contraction time (9 sec in total) induced muscle fatigue that was sufficient to mask a possible beneficial effect of PAP, with the fatiguing effect being greater as time elapsed. The decrease in peak leg power output after 8 and 12 min of recovery may be explained by considering the balance between potentiation and fatigue following a preconditioning contraction. Following a short duration pre-stimulus of high intensity exercise, the muscle is under both a fatigued and a potentiated state and the subsequent muscle performance depends on the interplay

between these two factors and the rate of recovery following the performance activity (Tillin and Bishop, 2009). Thus, it is possible that the potentiating effect was at least equal with the fatigue effect during the first 8 min of recovery, while after this time point the PAP effect was outbalanced by the effect of fatigue. Similar findings of long lasting fatigue after isometric exercise have been reported previously (Behm et al., 2004; Hamada et al., 2003). It has been argued that PAP may develop quicker than fatigue and that a greater volume of PAP contraction may result in the dominance of fatigue in the PAP-fatigue relationship (Tillin and Bishop, 2009).

To date, there is no uniform agreement about the most effective method and protocol to elicit a PAP response. Rixon et al. (2007) examined the influence of an isometric or dynamic squat protocol on PAP as demonstrated by changes in CMJ performance. Both protocols produced significant PAP results with isometric condition to cause larger improvements compared to dynamic and control conditions respectively. On the other hand, Till and Cooke, (2009) in a recent study compared a dynamic (5 set of 5RM) an isometric (3 sets of 3 sec) maximal voluntary knee extensions and a plyometric (5 tuck jumps) PAP treatments and found no significant differences between the conditions in sprint and vertical jump performance.

A number of studies have used a variety of methods to elicit a PAP response (Hodgson et al., 2005; Sale, 2002). Only a few studies have assessed the effects of PAP in the vertical jumping performance comparing dynamic and isometric protocols (Rixon et al., 2007; Till and Cooke, 2009) and only one study has been conducted to examine both the upper and lower body explosive activity after a preload stimulus of 3RM (Kilduff et al., 2007). Despite a number of PAP studies showing enhancement of performance (Baker, 2003; Chatzopoulos et al., 2007; Gourgoulis et al., 2003), several studies have reported no effect or even slight decrease in power output following different preload stimulus, rest periods and using subjects of different training status (Ebben et al., 2000; Hanson et al., 2007; Till and Cooke, 2009).

The equivocal findings among the above mentioned studies may be due to a number of factors including intensity and volume of the preload exercise, duration of the rest intervals between the consecutive sets and before execution of the performance activity and gender, level and relative or absolute strength appeared to influence the ability of subjects to utilize PAP. In the present study we compared different types of muscle contractions (isometric vs. plyometric) on the upper and lower performance in both male and female fencers, while the strength of the subjects was taken in account. A recent PAP study has utilized 5 double-legged tuck jumps which may have not been enough to enhance the excitability of the fast twitch motor units to create a PAP effect (Till and Cook, 2009). Therefore, in the present study we used a 3 sets protocol as it was proposed by Till and Cooke, (2009) in order to induce greater exercise volume which in turn could augment peak leg power during a CMJ. However, fencers' CMJ performance after this plyometric protocol remained unaffected. Similar results were also presented

by Esformes et al. (2010), who found no additional benefit after a set of 24 plyometric contacts in subsequent countermovement jump performance in thirteen anaerobically trained male subjects. This plyometric exercise was chosen because is empirically used and suggested by the fencing trainers as part of warm-up and strength programs for well trained fencers. It is possible that the load used in our study was too fatiguing and any PAP was masked by fatigue (Sale, 2002). Unfortunately in the present study, as also in others (Esformes et al., 2010; Masamoto et al., 2003) electromyography was unavailable, making the explanation on the mechanics by which plyometric exercises enhance stretch-shortening cycles performance.

The isometric protocol of the present study (3 set of 3 sec) has been previously used in other studies (French et al., 2003; Till and Cook, 2009). However, the rest period between contractions seems to be important in eliciting a PAP response. French et al. (2003) used an adequate 3-min rest period and found improved drop jump and knee extension performance, while the 15 sec short-rest used by Till and Cook, (2009) did not significantly change sprinting and vertical jump performance. The results of our study are consistent with the lack of positive effects, with an actual decrease of performance in males.

The majority of studies have used recovery periods of approximately 4 minutes (Comyns et al., 2006; Jensen and Ebben, 2003; Kilduff et al., 2007), while Terzis et al. (2009) reported significant PAP effects immediately after the preload exercise intervention. The results of our study are in contrast with the complex training studies that used intervals of approximately 4 min revealing improvements in the subsequent plyometric exercise (Gullich and Schmidtbeicher, 1996). However, previous research related to complex training has noted that the rest period between the resistance stimulus and the plyometric performance should be determined individually (Comyns et al., 2006). Kilduff et al. (2007), have examined the optimal recovery period to maximize the PAP effect after a preload stimulus of 3RM in bench press throw and CMJ performance. They reported a significant similar decrease in power performance in both the upper and lower body when the explosive activity was performed immediately after the preload stimulus as in our study. It is likely that similar mechanisms are responsible for the fatigue associated with the preload plyometric exercises of the present study.

Regarding lower body power, the results of this study are consistent with the findings of Comyns et al. (2006), who reported a reduction in CMJ performance after 6 min of recovery. Although no significant changes were evident immediately after the isometric protocol for both the upper and lower performance, CMJ and bench press throwing performance were found to be decreased immediately after the PAP treatment. Similar results were also observed by Jensen and Eben, (2003), who extensively examined the PAP effect within a 4 minutes recovery period and reported no significant differences at any time point. Moreover, Smith and Fry, (2007), suggested that 7 minutes of rest after an isometric PAP inducing stimulus, does not appear to affect power, force or velocity during the knee extension performance. On the other

hand, Evans et al. (2000) and Young et al. (1999) found significant ergogenic effects after 4 minutes of rest of the PAP induced exercises.

Training status or/and strength level and gender may affect the response capacity for PAP. It has been suggested that highly trained individuals (Ebben et al., 2000), the stronger athletes (Gourgoulis et al., 2003; Rixon et al., 2007) and those with the greater percentage of type II (Hamada et al., 2000) perform better and might benefit from a warm-up induced PAP exercises in comparison to recreational trained and weaker athletes. The results of the present study showed significant moderate correlations between the leg strength and the differences in performance after 12 min in comparison to the baseline for the isometric intervention, suggesting that strength may be a factor of interest as it appears to influence the balance between fatigue and the ability to utilize PAP (Jensen and Ebben, 2003; Kilduff et al., 2007; Robbins and Docherty, 2005). Theoretically, individuals that perform at higher levels may have a greater muscle activation which may in turn increase phosphorylation of myosin regulatory light chains and cause a greater alteration in α -motoneuron excitability that are linked to the PAP phenomenon (Hodgson et al., 2005). However, those individuals may also have a greater and longer lasting fatigue that may actually result in a decrease rather than increase of performance (Hamada et al., 2003).

Conclusion

In conclusion, the results of the present study indicated that plyometric exercise that are commonly used as part of the warm-up routines of elite fencers do not offer any performance advantage in either CMJ or bench press throwing performance. On the other hand isometric pre-conditioning exercise resulted in a decrease in peak power output of the legs, possibly due to neuromuscular fatigue, while the fencer's strength level and the gender played an important role in the balance between PAP and fatigue. Consequently, fencers should be advised against using isometric exercises to induce PAP at the volumes and load prescribed in the present study when aiming to augment lower body power performance.

Practical applications

The present results are specific to fencing and may not necessarily be directly applicable to other sports, although PAP can be utilized in power related disciplines and sport activities requiring high initial rates of force development (Sale, 2002). It should be noted that PAP varied greatly between individuals (Till and Cooke, 2009), however more studies are needed in order to determine the best conditioning activity protocol and the most appropriate design factors affecting subsequent performance. Additionally, it is still to be clarified whether PAP effects improve power output during specific kinetic patterns of fencing such as lunge or fleche.

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Key points

- Significantly lower values for peak power of the legs were noted in men at 8 and 12 min of recovery in response to the PAP protocol used in this study
- There is some evidence to suggest that stronger individuals may have a greater and longer lasting fatigue that may actually result in a decrease rather than increase of performance after a PAP protocol
- Fencers should be advised to avoid the use of isometric exercises in warm-up routines to augment explosive performance

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