ABSTRACT

Purpose. Muscle post-activation potentiation (PAP) is a mechanism by which power twitch is increased after previous conditioning contractions. In this study, we determined the time-dependent effect of a loaded drop-jump protocol on sprint time and countermovement jump height in well-trained athletes. Methods. Ten athletes randomly performed the control and experimental protocols on two different days. As a pre-test, the athletes performed the vertical jump and 50 m sprint test for preload measurements. Then, the experimental or control protocol was randomly applied, where the control protocol was composed of the athletes remaining at rest for 10 min. In the experimental protocol, the athletes performed two sets of 5 drop jumps (0.75 m), with a 15 s interval between the jumps and a 3 min rest after each set. Then the vertical jump and 50 m sprint tests were performed again 5, 10, and 15 min after the protocol. Results. The experimental condition (drop jump potentiation protocol) increased performance in the vertical jump by 6% after 15 min ($p < 0.01$) and in the sprint by 2.4% and 2.7% after 10 and 15 min, respectively ($p < 0.05$). Conclusions. These findings suggest that the drop jump potentiation protocol increases countermovement vertical jump and sprint performance in high-performance athletes at different times, suggesting that PAP induction depends not only on the design of the protocol, but also on the effect of time and the type of exercise involved.

Key words: muscle post-activation potentiation, sprint, vertical jump, drop jump, performance

Introduction

The development of muscle power output is a determinant of sport performance, especially in track and field events that are composed of running short distances or vertical and horizontal jumps [1, 2]. Several training techniques for maximizing muscle power have been investigated in order to acutely improve sport performance, but the results found in literature are not conclusive [1].

Performance in sprint running is dependent on the ability to generate high velocity in a short time interval, which itself depends on numerous biomechanical, architectural and biochemical factors [3]. Various training approaches are commonly used to improve sprint performance, including sprint drills, overspeed training, strength training and plyometrics [4, 5]. Mero and Komi [6] suggested that the elastic properties of the muscles and their energy stores are necessary for

high performance in sprint events. This fact supports the importance of power training to develop sprint potential. Plyometrics is a training method that develops the ability of muscles to produce force at high speeds (power output) in dynamic movements. This training is composed of muscle stretch followed by an explosive concentric contraction, known as the stretch-shorten cycle (SSC) [7]. Kotzamanidis [5] found that 10 weeks of plyometric training improved jump ability and running velocity in prepubescent boys. Similarly, Rimmer and Sleivert [8] reported a significant increase in sprint performance following sprint-specific plyometric training for eight weeks in male participants who had no experience with this kind of training.

In regards to acute power enhancement, several studies suggest that performance is increased after different protocols of muscle potentiation [9, 10]. This increase of acute power output has been related to post-activation potentiation (PAP) [11, 12]. PAP is a mechanism by which muscle contractile ability is increased by a previous bout of maximal or submaximal contractions [1, 13]. The precise mechanisms involved in PAP activation still remain unclear. Some theories
have been suggested, such as an increase of phosphorylation in the light chains of myosin, which elevates the sensitivity of actin-myosin interaction to release Ca$^{2+}$ from the sarcoplasmatic reticulum [13, 14], the modification of reflex activity in the spinal cord (H-reflex) [15], and the recruitment of a high number of motor units [1]. Previous studies have demonstrated that the manifestation of PAP depends on muscle characteristics, such as training status (particularly strength levels) [16], the distribution of fiber type [17], the contractile conditions (whether shortening or lengthening) [18], as well as an individual’s training background (greater PAP in power athletes when compared to endurance athletes) [19].

Several potentiation protocols have investigated the effects of maximal and submaximal muscle activity on subsequent athletic performance [11, 20]. Traditionally, PAP has been induced by an application of a strength training stimuli (preload), such as a heavy-load squat [11, 21] and maximal voluntary isometric contraction [19]. Masamoto et al. [22] observed that one repetition maximum (1RM) performance was increased (by 3.5%) in trained athletes when executed 30 s after one set of two depth jumps. Young et al. [10] reported that a single set of 5 maximal repetitions of squats increased countermovement jump height (by 2.8%) when performed 4 min later in athletes experienced with squat exercise. Kilduff et al. [23] also found an improvement in countermovement jump performance (by 4.9%), determined after 8 min (post 8 min) of squat potentiation protocol (three sets of 3 repetitions at 87% 1RM). Weber et al. [24] found an enhanced peak height of squat jump (by 4.7%) when completed 3 min after one set of 5 repetitions of back squat jumps at 85% of 1 RM in track and field athletes. Smith et al. [10] reported an increase in power output in a 10 s sprint cycle test when performed 5 min after ten sets of 1 repetition of parallel back squats at 90% 1RM. McBride et al. [21] observed an improvement in 40 m sprint time (by 0.87%) in football players after 4 min of doing one set of 3 repetitions of heavy-loaded squats at 90% of 1RM. Chatzopoulos et al. [25] showed that 10 repetitions of heavy resistance stimulus at 90% of 1RM was able to improve running speed in the 10 and 30 m dash in amateur players of team games when executed 5 min later.

Although several potentiation protocols have demonstrated an improvement in sport performance, some studies did not find any effect. Scott and Docherty [20] observed that one set of 5 maximal repetitions of back squats has no effect on maximal jump height and distance measured 5 min later in resistance-trained men. McBride et al. [21] related that one set of 3 repetitions of loaded-countermovement jumps (CMJ) does not improve performance in the 40 m sprint when performed 4 min later. Hanson et al. [26] demonstrated that a single squat performed at 80% of 1RM does not improve vertical jumping performance when measured immediately after the potentiation protocol in resistance-trained athletes. Parry et al. [13] observed that 5 back squats at 90% of 1RM have no effect on maximal cycle ergometer performance when executed 20 min later in male rugby players. Moreover, Lloyd and Deutsch [27] did not observe any effect on sprint performance after a 3-repetition maximum squat (post-10 min) and showed an impairment in 5 m split and 20 m sprint times (post-10 min) by the countermovement jump potentiation protocol.

Thus, several methods to induce PAP have been suggested and studied in order to improve output power performance. However, it is difficult to compare the results as there are several factors involved in PAP induction, such as protocol design, maximal induction time, sport modality, fiber type distribution, contractile conditions as well as an individual’s training background. Data available in literature on muscle PAP protocols and output power performance are not yet conclusive. Moreover, PAP induction at different times by the same experimental protocol in two different high power exercises has also not yet been investigated. Therefore, in this study we propose to evaluate the acute effects of one potentiation protocol (two sets of 5 repetitions of drop jumps) at different times (at pre-load and post 5, 10 and 15 min) on the performance of two high power exercises (the sprint time in the 50 m dash and countermovement jump [CMJ] height) in track and field athletes who have had at least 6 years of training experience in order to avoid any possible adaptation effects to the training protocol. This study was conducted as a randomized cross-over trial, where all participants performed the control and experimental protocols on two different days.

**Material and methods**

Ten male athletes were selected among the sprinters that represented the city of Guarulhos, Brazil in official track and field competitions. The participants were high-level professional athletes, regularly involved in jumping, sprint, stretching and power training activities and were experienced in both training and competition for at least six years. The age, body mass, and height of the group was: 20.6 ± 2.6 years; 73.7 ± 9.22 kg; and 176.4 ± 5.81 cm, respectively. Before involvement in the study, the athletes were informed about the objectives and methods of the study and signed a voluntary consent form. The athletes were instructed and accompanied at all times by a professional physical trainer in order to ensure that all of the procedures and techniques used in this study were performed correctly. This study was approved by the Research Ethics Committee from Cruzeiro do Sul University, São Paulo, Brazil (165/2008).

All of the participants randomly performed both...
the control and experimental protocols during two visits with 72 h rest between them in order to eliminate any possible crossover effects from the previous test. In addition, 24 h rest was given before the first day of testing. Just before each of the protocols, the athletes were submitted to a standardized warm-up (consisting of aerobic and stretching exercises).

Figure 1 illustrates the protocol conditions used in this study. Each protocol condition was performed on a different day. The control condition was composed of a standardized warm up, followed by 5 min rest. For pre-test measurements, the participants’ countermovement jump (CMJ) and 50 m sprint results were determined. After the pre-test, the athletes had 5 min of rest and remained resting for an additional 5 min (as part of the control condition). Then they subsequently performed the CMJ and the 50 m sprint test again at intervals of 5 min, 10 min and 15 min after the control condition (rest).

The experimental condition was composed of a standardized warm up, followed by 5 min rest and then the CMJ and 50 m sprint test (for pre-test measurements). After the pre-test and 5 min rest, the athletes performed a drop jump (DJ) potentiation protocol composed of two sets of 5 drop jumps at a height of 0.75 m and were instructed to react as fast as they could to immediately execute a vertical jump. Two sets of 5 drop jumps were performed with 15 s rest between the jumps and 3 min rest between the sets. Finally, after the drop jump sets, the athletes subsequently performed the CMJ and 50 m sprint test 5, 10, and 15 min after the DJ potentiation protocol.

The CMJ test was performed with an initial movement that began with an extended leg position with the trunk in the upright position and the hands placed at the hips. The athletes then performed an eccentric-concentric action that finished with a vertical jump. An electronic contact mat platform system (Multisprint, Hidrofit, Brazil) was connected to a computer that was used to measure the vertical jump height based on flight-time [28].

The 50 m sprint time was assessed at an outdoor track, where an infrared timing system (Multisprint, Hidrofit, Brazil) with 0.001 s accuracy was used. The sensors were positioned at 0 m and 50 m of the track to record the beginning and end of the race. The participants started each sprint from a three-point stand position and were instructed to accelerate and run as fast as possible. Wind speed was monitored throughout the entire experiment using a digital portable anemometer (AD-250, Instrutherm, Brazil). All the procedures were performed at the same time of day and the maximum wind speed limit adopted for the experiments was 2.0 m/s, the same benchmark adopted by the IAAF during official outdoor sporting events.

The results were analyzed using statistical software (GraphPad Prism 5®, San Diego, USA). First, the data were submitted to the Shapiro-Wilcox normality test and then analyzed by one-way ANOVA with repeated measures followed by Tukey’s multiple comparison post-hoc test. Data were considered significant when $p < 0.05$.

**Results**

The obtained sprint results for both the experimental and control conditions are presented in Table 1 (individual values) and Figure 2 (as mean ± standard error of the mean [SEM]). There was a significant difference in the 50 m dash time between the experimental and control conditions at the post-10 and post-15 min intervals (6.361 ± 0.23 s vs. 6.516 ± 0.24 s and 6.299 ± 0.24 s vs 6.468 ± 0.25 s) of −2.4% and −2.7% ($p < 0.05$), respectively. In addition, a significant reduction in the 50 m sprint time was observed in the experimental condition at post-10 and post-15 min by −1.4% and by −2.4% ($p < 0.05$), respectively, when compared to the pre-test (6.452 ± 0.23 s vs 6.361 ± 0.23 s and 6.452 ± 0.23 s vs 6.299 ± 0.24 s) ($p < 0.01$). Sprint time was also decreased in the experimental condition at post-15 min by −1.8% ($p < 0.01$) when compared to the post-5 min interval (6.299 ± 0.08 s vs 6.415 ± 0.07 s).

The results of the CMJ height for the experimental and control conditions are presented in Table 2 (individual values) and Figure 3 (mean ± SEM). Similarly to sprint performance, the experimental protocol led to a significant increase in CMJ height at post-15 min by +5.5% (45.8 ± 0.66 cm vs 43.4 ± 0.86 cm; $p < 0.01$) when compared to control condition. In addition, the
Table 1. The sprint time of the 50 m dash (in seconds) of the study participants

<table>
<thead>
<tr>
<th>Participant</th>
<th>Pre-test control</th>
<th>Pre-test experimental</th>
<th>Post-5 min control</th>
<th>Post-5 min experimental</th>
<th>Post-10 min control</th>
<th>Post-10 min experimental</th>
<th>Post-15 min control</th>
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S.E.M         | 0.0331         | 0.0733               | 0.0280             | 0.0748                  | 0.0356              | 0.0725                 | 0.0355               | 0.0753                 |

Table 2. The maximal vertical jump height (in cm) of the study participants

<table>
<thead>
<tr>
<th>Participant</th>
<th>Pre-test control</th>
<th>Pre-test experimental</th>
<th>Post-5 min control</th>
<th>Post-5 min experimental</th>
<th>Post-10 min control</th>
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Mean          | 44.19          | 44.08                | 43.69              | 43.19                   | 43.03               | 44.32                  | 43.44               | 45.84                  |

S.E.M         | 0.770          | 0.635                | 0.653              | 0.754                   | 0.862               | 0.820                  | 0.860               | 0.662                  |

Figure 2. The sprint time of the 50 m dash. The time was measured at different moments: before preload (Pre), post-5 min (Post-5), post-10 min (Post-10) and post-15 min (Post-15)

Figure 3. The maximal vertical jump height. The height was measured at different moments: before preload (Pre), post-5 min (Post-5), post-10 min (Post-10) and post-15 min (Post-15)
CMJ height significantly increased in the experimental condition at post-15 min when compared to the pre-test values by +4% (45.8 ± 0.66 cm vs 44.3 ± 0.63 cm; \( p < 0.01 \)) and post-5 min by +6.1% (45.8 ± 0.84 cm vs 43.2 ± 0.75 cm; \( p < 0.001 \)) in the same (experimental) condition.

**Discussion**

Muscle PAP is a mechanism by which power twitch is increased after previous conditioning contractions [1, 12, 13]. Since there are various factors involved in PAP induction and since the time of maximal induction has not yet been investigated, this study evaluated the effects of a DJ potentiation protocol on sprint time and CMJ height performance in well-trained athletes at different times. It was found that the DJ potentiation protocol was effective in inducing PAP and improving performance in both the 50 m dash and vertical jump. Sprint time decreased after 10 and 15 min and CMJ height increased after 15 min in the experimental condition (DJ potentiation protocol), suggesting that the time for maximal PAP induction is specific for different high power exercises.

As previously mentioned, strength-exercise induced PAP has been shown to be effective in considerably increasing CMJ height. Young et al. [10] observed an improvement in loaded-CMJ height of 2.8% in athletes 4 min after performing one set of 5 maximal repetitions of squats. Our DJ potentiation protocol induced an increase in CMJ height only at post-15 min. We believe that the difference is due to the design of the experiment. In the Young et al. [10] study, the athletes executed two sets of 5 loaded CMJ (as pre-load), followed by the squat exercise potentiation protocol and finally by one set of 5 loaded-CMJ (post-load). An interval of 4 min between the sets was imposed and the results were compared between pre- and post-load. Thus, PAP induction of this protocol could have resulted from all of the performed exercise and not only from the squat exercise protocol. In fact, the total time between the first pre-load test and post-load test in the Young et al.'s [10] study was 16 min.

As previously discussed, not only is the time interval an important factor for maximal PAP manifestation, but also other factors which are involved in this process. These factors include the design of the potentiation protocol, the type of high power exercise and the experience of the athletes. It is difficult to compare our study to others as these factors vary greatly. PAP manifestation is observed at different time intervals after the potentiation protocols’ application in several studies. These post-load time intervals vary between 0.5 min and 20 min [10, 11, 23]. Thus, all these factors need to be considered when potentiation programs are used by athletes that intend to increase muscle power output.

A limited number of studies have investigated the effects of PAP manifestation on sprint time and running speed. When compared to other studies, our DJ potentiation protocol improved sprint time only at the post-10 min and post-15 min intervals. Some studies have found no effect of different potentiation protocols on sprint performance when the individuals were evaluated after a short time of the application (few minutes). Chatzopoulou et al. [25] found that a back half-squat potentiation protocol (10 single repetitions at 90% of 1RM) did not increase running speed post-3 min in a 30 m dash. McBride et al. [21] found that a loaded-CMJ protocol (one set of 3 repetitions) did not improve sprint time post-4 min in a 40 m dash. After the PAP protocols, both potentiation and fatigue could coexist and the balance between these two factors are determinants in the final performance of subsequent high power exercise [1, 26]. Previous studies have shown that a period of 4-5 min is required to restore creatine phosphate and the effectiveness of PAP can be found up to 20 min [10]. Therefore, in our study, the effect of fatigue may have a negative effect on PAP at 5 min after the DJ potentiation protocol.

However, McBride et al. [21] observed an improvement in 40 m sprint time (0.87%) in football players after 4 min of applying one set of 3 repetitions of heavy-loaded squat at 90% of 1RM, but no effect was found when the athletes were submitted to a loaded-CMJ protocol (one set of 3 repetitions) in the same study, demonstrating that the potentiation protocol design is an important factor for PAP manifestation. In our study, we found a decrease (non-significant) of 0.50% in sprint time by DJ potentiation protocol at the post-5 min interval when compared to the pre-test. At post-10 min and post-15 min, the reduction amounted to 1.4% and 2.4%, respectively. As discussed above and observed in our study, the post-load time interval was an important factor for PAP induction. Thus, it is possible that the improvement found by McBride et al. [21] would be higher if the time interval was more prolonged. Moreover, the effect of fatigue can be more pronounced in our design potentiation protocol than in the protocol used by McBride et al. [21].

**Conclusion**

The results obtained in this study suggest that muscle PAP programs are useful in increasing performance in high power exercises. However, several factors are involved in this process and need to be considered when these programs are used for training track and field athletes. These factors include the design of the potentiation protocol, the time required for maximal induction, the type of high power exercise and the experience of the athletes. The potentiation protocol used in this study (two sets of 5 DJ) is an acute power training method that can be used by coaches and physical
trainers in order to improve an athlete's speed in short distances and their performance in vertical jumps when competing. This protocol induced an improvement in 50 m sprint time after 10 min and 15 min and in a countermovement vertical jump after 15 min, demonstrating that the post-load time interval for increasing performance by DJ potentiation protocol in track and field experienced athletes varies according to the type of high power exercise involved. Additional studies are required to evaluate if different DJ potentiation protocols (e.g. different heights of the box for the DJ or the number of sets and drop jumps per set) can be more efficient for improving performance in sprint and CMJ.

In summary, our results suggest that the DJ potentiation protocol used in this study improves performance in sprint time and vertical jump in high performance athletes at different times, suggesting that the peak of PAP induction depends not only on protocol performance athletes at different times, suggesting that the type of high power exercise involved. Additional studies are required to evaluate if different DJ potentiation protocols (e.g. different heights of the box for the DJ or the number of sets and drop jumps per set) can be more efficient for improving performance in sprint and CMJ.

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