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Effect of post-activation potentiation in Athletics: a systematic review

Efeito da potencialização pós-ativação no Atletismo: uma revisão sistemática

Diego de Alcantara Borba[1,2,3]
João Batista Ferreira-Júnior[4,3]
Luniky Alves dos Santos[1]
Maria Carolina do Carmo[1]
Leonardo Gomes Martins Coelho[5]

Abstract – Post-activation potentiation is a physiological phenomenon reported to increase muscle performance during high-intensity exercise. To induce post-activation potentiation, maximal strength or power short-duration activities are performed minutes prior the main activity in an attempt to enhance performance. The aim of this study was to evaluate previous publications on the effects of post-activation potentiation on athletic performance. This systematic review used Scielo, Pubmed and SporDiscus database with the following search terms either alone or grouped together: *post-activation potentiation, exercise, athletics, track and field, sprint, long jump, triple jump, high jump, shot put, javelin throw, hammer throw* e *discus throw*. The review provided evidence that performing squat, jump and sprint exercises prior to the main activity elicited a state of potentiation that would improve sprint and throw performances and that preparatory activities that can cause post-activation potentiation should be used to improve athletic performance.

Key words: Jumping; Preparation; Running; Throwing; Warm-up.

Resumo – *A potencialização pós-ativação é um fenômeno fisiológico capaz de aumentar o desempenho muscular durante exercícios de alta intensidade. Para induzir a potencialização pós-ativação, atividades de curta duração com força máxima ou potência muscular são realizadas minutos antes da atividade principal na tentativa de aumentar o desempenho. O objetivo deste estudo foi avaliar as publicações anteriores sobre os efeitos da potencialização pós-ativação sobre o desempenho no atletismo. Esta revisão sistemática utilizou os bancos de dados Scielo, Pubmed e SportDiscus com os seguintes termos de pesquisa juntos ou separados: post-activation potentiation, exercise, athletics, track and field, sprint, long jump, triple jump, high jump, shot put, javelin throw, hammer throw e discus throw. A revisão evidenciou que a realização de agachamentos, saltos e sprints, antes da atividade principal, desencadeia o estado de potencialização, que então aumenta o desempenho de sprints e lançamentos, e que atividades preparatórias que causam potencialização pós-ativação podem ser utilizadas para aumentar o desempenho no atletismo.*

Palavras-chave: *Aquecimento; Corrida; Lançamento; Preparação; Salto.*

1 University of the State of Minas Gerais. Department of Human Movement Sciences, Faculty of Physical Education. Ibirité, MG. Brazil.

2 University Foundation of Itaúna. Faculty of Physical Education. Itaúna, MG. Brazil.

3 Catholic University of Minas Gerais. Department of Physical Education. Belo Horizonte, MG. Brazil

4 Federal Institute of Education, Science and Technology of Southeastern Minas Gerais. Rio Pomba, MG. Brazil.

5 Federal Center of Technological Education of Minas Gerais. Divinópolis, MG. Brazil.

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INTRODUCTION

Post-activation potentiation (PAP) is a physiological event indicated as a potentiator of muscle strength[1]. This physiological event would be caused by the performance of conditioning exercises before the main activity, leading to an increase in the speed of conduction of the nerve impulse to the muscle, number of recruited motor units and improvement in the interaction mechanism of contractile filaments[1-3]. By means of neuromuscular changes, PAP may contribute to improve the performance in exercises that require strength, power or speed[2,3].

The first studies on this subject dates back to the beginning of the 20th century, in which muscle tension increases in isolated fibers after maximal tetanic contraction induced by electrical stimulation were detected, which is known in literature as post-tetanic potentiation (PTP)[4].

The phenomenon of potentiation is also verified with the use of the *in situ* technique. The standard procedure consists of surgical removal of muscle from the anesthetized animal without loss of nerve and blood supply. The muscle is then artificially stimulated through its main nerve[5]. In both *in vitro* and *in situ* procedures, PTP was elevated immediately after tetany and reduced in the subsequent 10 minutes[4]. Like PAP, PTP is often associated with short periods of contraction and relaxation[6].

The first studies that used voluntary contractions as a means of promoting potentiation date back to the 1980s, in which the main aim was to investigate and understand the molecular mechanisms responsible for PAP through animal and human models[7,8]. In the *in vivo* procedure, the potentiating mechanism of muscle contraction is the exercise itself. Increased strength is caused by previous high-intensity physical exercise. In this case, PAP is investigated by increased muscular tension or performance in specific tasks that require strength or power, with biopsy and electromyography being the most used means to analyze its mechanisms[1-3].

Previous studies have investigated the influence of some variables on PAP manifestation, such as age[9], type of motor unit recruited[10], training level[11] and the effect of sex[12]. In short, all these variables, at least at some point, were modulators of PAP.

Currently, several types of PAP induction protocols are applied in order to improve acute physical performance. Among them, squat[13-15], jump[16-18] and sprint[16,19,20] protocols stand out. In all of these studies, significant performance differences after potentiation protocol were found ($p < 0.05$). However, PAP presents great individual variability, which suggests that its presence also depends on the sample characteristics and types of conditioning exercises[3,9,12,11,12]. Thus, it cannot be said that PAP is always synonymous of increased performance.

To achieve PAP, strength / power exercises differ from traditional preparatory exercises (warm-up) in relation to their characteristics and physiological mechanisms. Traditional warm-up exercises are composed of low-intensity aerobic activities, stretching exercises of the main muscles and

specific movements of the modality, and their duration is quite varied[21]. As the name suggests, the main aim of warm-up exercises is to increase body temperature. The increase in central and muscular temperature alters several physiological functions that would improve physical performance[21]. Among the physiological changes promoted by warm-up exercises, increased blood perfusion and oxygen consumption stand out, which would reduce the period of oxygen deficit of the beginning of activity, anticipating the beginning of the steady state[22]. In addition, increased muscle temperature would reduce joint and muscle fiber stiffness during exercise, resulting in more coordinated and faster movements[23]. The literature also points out that high muscle temperature improves the speed of conduction of nerve impulses, which may contribute to the improvement of performance in strength and power exercises[24,25].

PAP can be triggered by exercises that require production of maximum or near maximum muscle power and strength, using short-duration exercises with weights and jumps, which main function is to improve the production of strength and power during effort[1,18]. The possible physiological mechanisms of PAP are related to central and peripheral mechanisms. PAP may occur as a result of the alteration in the stimulation pattern of motor units, resulting in an increase in the number of excited motor units, improved synchronization of nerve impulse firings, reduction of central inhibitory mechanisms (Renshaw cell and Golgi tendon organ) and increased reciprocal inhibition of the antagonist musculature[3,26].

In relation to muscular mechanisms, PAP is associated with a better approximation of myosin globular heads for interaction with actin[1]. This better positioning would favor greater connections among protein filaments and, consequently, greater development of muscle tension[1]. In addition, PAP may be linked to increased Ca^{2+} concentration in sarcoplasm, implying greater phosphorylation of light-chain myosin, as well as greater formation of cross-bridges[3].

However, it is noteworthy that there are mechanisms that determine whether exercise before the main activity will cause muscle strength increase (potentiation) or decrease (fatigue). The interval between exercises will determine whether the conditioning exercise will be detrimental or will improve performance[27]. If the main activity occurs immediately after the conditioning activity, fatigue could predominate over potentiation. The opposite may occur when sufficient interval for muscle recovery is allowed between activities. In this situation, muscle strength would be increased[28].

According to MacIntosh et al.[3], the ideal time for potentiation is from one to five minutes because this is the time in which light-chain myosin remains phosphorylated, creating, according to the authors, a contraction "memory". Above this period, this memory is dissipated and potentiation is impaired. However, the meta-analysis study by Wilson et al.[29] indicates that the ideal period between preparatory activity and main activity would be between seven and ten minutes (effect size of 0.7), compared to intervals of less than two minutes, between three and seven minutes and over 10 minutes (effect size of 0.17, 0.54 and 0.02, respectively).

Other factors that may modulate the effects of potentiation are the types of motor units recruited and the training level[30]. Studies indicate that the potentiation mechanisms are more common in type-IIx motor units, also denominated fast contraction, since these units have higher velocity of nerve impulse conduction and better phosphorylation capacity of light-chain myosin compared to type I units[11]. This mechanism also explains why subjects who are experienced in strength training benefit better from potentiation strategies compared to inexperienced subjects, since strength training improves the recruitment of type II units, especially type IIx units[31].

PAP has been studied in several sports, including athletics, which includes different specific modalities such as running, jumping and throwing. One of the marked characteristics of athletics is its direct relation to physical capacities such as speed and explosive strength in the 100 meters and weight throwing, respectively. Maćkała et al.[32] found a significant inverse correlation (r = -0.71) between the time to run a 10-meter distance and the performance in the maximal repetition strength test (1RM) of the lower limbs in 11 elite sprinters. Judge et al.[33] found high association between performance in weight throwing and the 1RM test in weight lifting exercise (male group r = 0.82 and female group r = 0.89). Thus, athletics seems to be a great scenario for PAP evaluation in sports performance.

In this sense, it is possible that the performance of conditioning activities that induce PAP increase acute performance in athletic events that require great muscular strength manifestation. Therefore, the aim of the present study was to evaluate the effects of potentiation activities on performance in athletics events. This information can help coaches and athletes in the planning of conditioning activities that lead to improved sports performance in competitions.

METHODOLOGICAL PROCEDURES

Articles of the topic above were selected through bibliographic research on Scielo (Scientific Electronic Library Online), Pubmed and Sportdiscus databases. The terms used in the research were: post-activation potentiation, exercise, athletics, field and track, sprint, long jump, triple jump, high jump, shot put, javelin throw, hammer throw and discus throw. These terms were used both separately and in groups. On the Scielo database, the same terms were used in Portuguese language. Articles that had evaluated subjects who practiced athletics, regardless of gender, age, level and purpose of practice were considered.

In the first consultation, approximately 1860 articles were found. In the second search filter, only terms post-activation potentiation associated with modal terms (e.g., post-activation potentiation + shot put or post-activation potentiation + 100m) were used, and 154 articles were found. The abstract of each article was consulted and the articles selected for review were those that presented the following criteria: a) to be an experimental study; b) to

evaluate the effects of conditioning activities of strength or muscular power on the PAP of some athletics modality; c) year of publication within the last 10 years and d) to be written in Portuguese or English. Thus, eight articles remained for evaluation.

RESULTS

The characteristics of the population investigated by studies found in the present review are summarized in Box 1.

Box 1. Characteristics of the population investigated by studies

	Variables				
Studies	Sex	Mean Age (years)	Mean Weight (kg)	Mean Height (m)	Training Level
Karampatsos et al.[16]	M	26	113.4	1.84	Athlete
Terzis et al.[34]	M/F	23/22	77/66	1.77/1.70	Physically active
Terzis et al.[35]	M	24	110.4	1.82	Athlete
Evetovich et al.[36]	M/F	20	73.3/59.8	1.78/1.69	Athlete
Kummel et al.[37]	M/F	22	99/79	1.86/1.81	Athlete
Esformes et al.[38]	M	22	82.7	1.82	Athlete
Linder et al.[39]	F	20	58.4	1.60	Physically active
Lim and Kong[40]	M	22	67.6	1.74	Athlete

M = male; F = female

This section also presents studies that evaluated the effects of some potentiation protocols on performance in different athletics modalities (Box 2).

Terzis et al.[34] evaluated the effects of five deep jumps (40 cm in height) on the performance of the frontal weight throw (6 kg for male group and 4 kg for female group) with both hands in eight university men and eight women training throw. The results showed improved performance 20 s after conditioning activity (Pre = 8.25 ± 1.1 m, Post = 8.63 ± 1.3 m, $p < 0.01$). In a similar protocol, Terzis et al.[35] evaluated the effects of three counter-movement jumps over the throwing distance of experienced athletes and also found improvement in performance one minute after conditioning activity (Pre = 15.45 ± 2.36 m, Post = 15.85 ± 2.41 m, $p = 0.0003$). Evetovich et al.[36] also found an increase in weight throw distance (without conditioning activity = 11.77 ± 1.81, with conditioning activity = 11.91 ± 1.81 m, $p \leq 0.05$) in 10 university athletes of both sexes after 3RMs in leg extension five minutes after conditioning activity.

Kummel et al.[37] showed that 10 consecutive horizontal jumps with double support increase by 11% (without conditioning activity = 0.31 m, with conditioning activity = 0.38, $p < 0.05$), the mean height of eight consecutive deep jumps (10 seconds interval between conditioning and main activity) but did not find improvement in the 30-m run performance after 10-20 s intervals between activities ($p > 0.05$). Karampatsos et al.[16]

found greater distance in hammer throw one minute after three counter-movement jumps (Pre = 62.92 ± 4.43 m, Post 64.42 ± 5.13 m, p = 0.047) and one minute after 20-m sprint (Pre = 64.87 ± 3.90 m, post = 65.30 ± 4.02 m, p = 0.013) in six experienced male hammer throwers. However, Esformes et al.[38] analyzed the effects of 24 plyometric jumps with alternating legs on the height of counter movement jump (CMJ) in well-trained adult jumpers and sprinters and found no difference in CMJ after five minutes of interval between conditioning activities (p> 0.05). According to the author, the duration of jumps used in the study was too long, which required less intensity for its accomplishment. This situation could have led to predomination of fatigue mechanisms over potentiation ones, reducing the activation of motor units.

In addition to jumping, another exercise widely used to induce PAP in athletics athletes are squats. Esformes et al.[38] analyzed the effects of a series of 3RMs of squats on the height of counter movement jumps (CMJ) in well-trained jumpers. The interval between conditioning activity and main activity was five minutes. The results showed higher CMJ height after performing squatting compared to control situation (p = 0.01). Linder et al.[39] investigated the effect of a series of 4RMs on squatting on the 10-meter running speed in 12 young females and the results indicated improvement of 0.19 seconds (1.2%) in the running time nine minutes after the squatting protocol (Pre = 17.14 ± 1.55, Post = 16.95 ± 1.55). Evetovich et al.[36] found an increase in vertical jump height (Pre = 61.9 ± 12.3 cm; Post = 63.6 ± 11.6 cm) and horizontal jump distance (Pre = 93.7 ± 11.0 cm; Post = 95.9 ± 11.5 cm) eight minutes after three squat series at 85% 1RM squats in Athletic university athletes of both sexes. On the other hand, Lim and Kong [40] evaluated the effects of three conditioning protocols: 1) dynamic squatting, 2) maximal isometric knee extension, 3) maximal isometric squat contraction, and 4) control over 30m run performance in 12 speed running athletes. No significant difference was found in time to complete 30 m in situations with a four-minute interval between conditioning and main activity (p> 0.05).

Short-duration speed running events have also been used as potentiation exercises. Terzis et al.[35] investigated the effects of a 20-m run on the weight throwing distance in experienced athletes. The interval between potentiation and main activities was one minute. The results showed improvement in the distance reached after running (Pre = 15.34 ± 2.41, Post = 15.90 ± 2.46 m, p = 0.0007). Karampatsos et al.[16] found a significant increase in the hammer throw distance (Pre = 64.87 ± 3.90 m, Post = 65.30 ± 4.02 m; p = 0.013) one minute after 30-m run.

No study reported the duration of the conditioning activity performed.

Box 2. Synthesis of studies related to post-activation potentiation in athletics.

Author	Study population	Potentiation activities	Interval between activities	Main activity	Results
Karampatsos et al.[16]	Six male hammer throwers (26±3 years)	a) Three CMJ b) maximum run of 30 m	1 min	Hammer throwing	Longest distance reached by weight after both potentiation protocols.
Terzis et al.[34]	16 physically active students of both sexes (Men: 22±1 years; Women: 23±3 years).	Five deep jumps (40 cm).	20 s	Frontal throw of weight with both hands.	The throw distance was higher after the jumps in a single group of both sexes and in the male group
Terzis et al.[35]	10 male weight throwing athletes (24±4 years)	Three CMJ b) maximum run of 20 m	1 min	Weight throwing	Longest distance reached by weight after both potentiation protocols
Evetovich et al.[36]	1) 20 athletes of both sexes (20.2±2.0 years 2) 10 athletes of both sexes (20.6±0.7 years)	1) one series of 3 squats at 85% 1RM 2a) one series of 3RM in no leg extension. 2b) 3RM in squatting.	1) 8 min 2a and 2b) 5min	1) vertical jump height and horizontal jump distance 2a and 2b) weight throwing	A) Highest vertical jump height and longest horizontal jump distance. B) There was improvement in throwing distance only after the series of 3RM in bench press.
Kummel et al.[37]	Two women (23 ± 8 years) and three men (21 ± 2 years) international sprinters	10 consecutive horizontal jumps	a) 10 s b) 10-20 s	a) Average height of eight depth jumps b) maximum running of 30 m	There was an improvement in the average height of deep jumps, but not in the time of 30-m run after the potentiation protocol
Esformes et al.[38]	13 men competing for speed and jumping events (22 ± 3 years)	a) a series of 3RMs in squatting b) 24 plyometric jumps with alternating legs	5 min	Vertical jumping with counter movement (CMJ)	Greatest CMJ height after squats compared to plyometric jumps. There was no effect of plyometric jumps on CMJ height
Linder et al.[39]	12 physically active women (20.8 ± 1.9 years).	4RMs in squatting.	9 min	100-m run.	Reduction in time to cover 100 meters
Lim and Kong[40]	12 trained male sprinters (22.4 ± 3.2)	a) dynamic squatting, b) maximum isometric knee extension c) maximum isometric squat contraction	4 min	Maximum running of 30 m	There was no effect of activities on time to complete the run.

DISCUSSION

The aim of this systematic review was to evaluate the effects of potentiation activities on performance in athletics events. Most studies found in the current review suggest the presence of post-activation potentiation in different athletics events[16,34,35,36,37,38,39]. This may be associated with neuromuscular and molecular changes induced by strength and power activities such as: 1) better recruitment of motor units, especially type-IIx motor units, which have a higher contraction velocity and capacity to generate tension; 2) increased availability of Ca^{++} for contraction and 3) increased phosphorylation of light myosin chains, facilitating the interaction of contractile filaments[1,3]. These mechanisms are more effective in type-IIx units, which help explaining the manifestation of PAP in trained athletes[2].

However, some exercise protocols did not improve performance in the main activity, suggesting the absence or insufficient PAP[28,40]. In general, the authors explain that the absence of significant results is associated with

inadequate type, duration and intensity of the conditioning activity. In addition, less-trained or female individuals have lower capacity to recruit type-IIx motor units compared to their male-trained pairs[31,35]. Therefore, potentiation mechanisms would be more evident in stronger and more trained athletes compared to weaker subjects[2].

In addition, PAP presents great individual variability[3,9,10,11,12], which suggests that there will not always be PAP after performing a conditioning activity. For example, Lin and Kong[40] observed PAP in only three subjects (n = 12), suggesting that the use of conditioning activities is not always effective in causing PAP. Thus, PAP is a volatile phenomenon and therefore is not always associated with increased performance[3]. It is important for coaches to consider individuality and type of conditioning activity used in order to improve the chances of obtaining PAP.

The time interval between PAP activity and the main activity directly influences the potentiation / fatigue relationship. The period adopted by studies ranged from 20 seconds to nine minutes. According to Wilson et al.[29], the ideal period between PAP activity and the main activity is between 7 and 10 minutes. Some authors suggest that, for intervals shorter than one minute, fatigue would predominate over potentiation mechanisms, decreasing performance, while for very long periods (> 12 min), potentiation would be dissipated[3,27,28]. However, there was an increase in athletic performance with interval of less than one minute[35].

Another factor that must be discussed regards the specificity of the conditioning activity in relation to the main activity. Most studies surveyed used body segments and similar muscles to perform the conditioning and main activity, for example, squatting / jumping, running / jumping, squatting / running[2,18,19,40]. Such protocols make sense, since PAP depends on biochemical alterations in the muscle[1,3]. However, some studies have also found potentiation after performing conditioning activities using body segments different from those required in the main activity[16,24,25]. This phenomenon reinforces the hypothesis that PAP is also associated with neural mechanisms, as observed by Gullich and Schmidtbleicher[24], who reported an increase in H-reflex after five seconds of maximal isometric contraction. Considering that the greater the amplitude of H waves, the greater the number of motor units recruited[1,8], this finding suggests that the accomplishment of maximum isometric contraction as a PAP activity increased the number of motor units recruited.

On the other hand, some points in common were observed among conditioning activities such as the requirement of maximum or near maximum effort with duration less than or close to one minute; exclusive use of lower limbs regardless of muscle group used in the main activity and interval between conditioning and main activities below 10 minutes. This homogeneity of protocols that promote PAP may be interesting for its application in athletics, facilitating its adaptation in the varied conditions and levels of competition performance.

This study has some limitations. In general, no study evaluating the

effects of conditioning activities in a competitive situation has been found in literature. Thus, it is not possible to conclude whether PAP was present in performance improvement during competition.

CONCLUSION

Most studies found in the present review showed that strength and power activities are able to promote PAP and improve the performance of subjects with different training levels in some athletics events. However, it is noteworthy that PAP presents great individual variability, suggesting that there will not always be PAP after performing a conditioning activity. Different intervals between conditioning activity and main activity (1 to 10 minutes) were shown to be adequate for potentiation manifestation. The main conditioning activities were those that required maximum voluntary dynamic contraction, such as squats, jumps and sprints, suggesting that strength and power preparatory activities can be applied during athletics competitions due to their quick and simple performance. Finally, the effects of strength and power conditioning activities should be investigated in other athletics modalities such as high jump, pole vault, distance jump, triple jump and discus and javelin throw. In addition, future studies could evaluate the chronic effects of the use of conditioning activities capable of promoting PAP to increase performance in athletics.

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REFERENCES

1. Batista MAB, Roschel H, Barroso R, Ugrinowitsch C, Tricoli V. Potencialização pós-ativação: possíveis mecanismos Fisiológicos e sua aplicação no aquecimento de Atletas de modalidades de potência. Rev Educ Fís/UEM 2010;21(1):161-74.
2. Xenofondos A, Laparidis K, Kyranoudis A, Galazoulas Ch, Bassa E, Kotzamanidis C. Post-activation potentiation: factors affecting it and the effect on Performance. J Phys Educ and Sport 2010;28(3):32-8.
3. MacIntosh BR, Robillard ME, Tomaras EK. Should postactivation potentiation be the goal of your warm-up? J Appl Physiol Nutr Metab 2012;(37):546–50.
4. Brown GL, Von Euler US. The after effects of a tetanus on mammalian muscle. J Physiol 1983;93:39–60.
5. Russell LM, Stull JT. Myosin light chain phosphorylution in fast and slow skeletal muscles in situ. Am J Physiol 1984;247 (Cell Physiol. 16): 462-71.
6. O'Leary DD, Hope K, Sale DG. Posttetanic potentiation of human dorsiflexors. J Appl Physiol 1997;83(6): 2131-8.
7. Palmer BM, Moore RL. Myosin light chain phosphorylation and tension potentiation in mouse skeletal muscle. Am J Physiol 1989;257:1012-9.
8. Hicks AL, Fenton J, Garner S, McComas AJ. M wave potentiation during and after muscle activity. Journal of Applied Physiology 1989;66: 2606–10.
9. Petrella RJ, Cunningham DA, Vandervoort AA, Paterson DH. Comparison of twitch potentiation in the gastrocnemius of young and elderly men. Eur J Appl Physiol 1989;58:395-9.

10. Hamada T, Sale DG, MacDougall JB, Tarnopolsky MA. Postactivation potentiation, fiber type, and twitch contraction time in human knee extensor muscles. J Appl Physiol 2000;88:2131-7.
11. Chiu LZF, Fry AC, Weiss LW, Schilling BK, Brown LE, and Smith SL. Postactivation potentiation responses in athletic and recreationally trained individuals. J Strength Cond Res 2003;17(4):671–7.
12. Rixon KP, Lamont HS, Bemben MG. Influence of type of muscle contraction, gender, and lifting experience on postactivation potentiation performance. J Strength Cond Res 2007;21:500-5.
13. Esformes JI, Bampouras TM. Effect of back squat depth on lower-body postactivation potentiation. Journal of strength and Conditioning research 2013;27(11):2997-3000.
14. Fukutani A, Takei S. Influence of the intensity of squat exercises on the subsequent jump performance. J Strength Cond Res 2014;28(8):2236-43.
15. Suchomel TJ, Lamont HS, Moir GL. Understanding Vertical Jump Potentiation: a Deterministic Model. Sports Med 2015: 1-12.
16. Karampatsos BG, Terzis G, Polychroniou C, Georgiadis G. Acute effects of jumping and sprinting on hammer throwing performance. J Phys Educ Sport 2013;13(1):3-5.
17. Sarramian VG, Turner AN,Greenhalgh AK. Effect of postactivation potentiation on fifty-meter freestyle in national swimmers. J Strength Cond Res 2015;29(4):1003-9.
18. Turner AP, Bellhouse S, Kilduff LP, Russell M. Postactivation potentiation of sprint acceleration performance using plyometric exercise. J Strength Cond Res 2015;29(2):343-50.
19. Smith CE, Hannon JC, McGladrey B, Shultz B, Eisenman P. Lyons B. The effects of a postactivation potentiation warm-up on subsequent sprint performance. Hum Mov 2014;15(1):36-44.
20. Hancock AP, Sparks KE, Kullman EL. Postactivation potentiation enhances swim performance in collegiate swimmers. J Strength Cond Res 2015;29(4):912-7.
21. Bishop D. Warm Up I: Potential Mechanisms and the Effects of Passive Warm Up on Exercise Performance. Sports Med 2003;33(6): 439-54.
22. Gerbino A, Ward S, Whipp B. Effects of prior exercise on pulmonary gas-exchange kinetics during high-intensity exercise in humans. J Appl Physiol 1996; 80(1): 99-107.
23. Faulkner A, Zerba E, Brooks SV. Muscle temperature of mammals: cooling impairs most functional properties. Am J Physiol Regul Integr Comp Physiol 1990;259(2):259-65.
24. Gullich A, Schmidtbleicher D. MVC-induced short-term potentiation of explosive force. New Stud Athlet 1996;11(4):67-81.
25. Young WB, Jenner A, Griffiths K. Acute enhancement of power performance from heavy load squats. J Strength Cond Res 1998;12: 82-4.
26. Hodgson MJ, Docherty D, Zehr EP. Postactivation Potentiation of Force Is Independent of H-Reflex Excitability. Int J Sports Physiol Perform 2008;3:219-31.
27. Rassier DE, Macintosh BR. Coexistence of potentiation and fatigue in skeletal muscle. Brazilian J Med Biol Res 2000;33(5):499-508.
28. Kilduff LP, Bevan HR, Kingsley MI, Owen NJ, Bennett MA, Bunce PJ, et al. Postactivation potentiation in professional rugby players: optimal recovery. J Strength Cond Res 2007;21(4):1134-8.
29. Wilson JM, Duncan NM, Marin PJ, Brown LE, Loenneke JP, Wilson SMC et al. Meta-analysis of postactivation potentiation and power: effects of conditioning activity, volume, gender, rest periods, and training status. J Strength Cond Res 2013;27(3):854-9.
30. Gourgoulis V, Aggeloussis N, Kasimatis P, Mavromatis G, Garas A. Effect of a submaximal half-squats warm-up program on vertical jumping ability. J Strength Cond Res 2003;17:342–4.

31. Balsalobre-Fernández C, Tejero-GonzálezCM, Campo-Vecino J, Alonso-Curiel D. The Effects of a Maximal Power Training Cycle on the Strength, Maximum Power, Vertical Jump Height and Acceleration of High-Level 400-Meter Hurdlers. J Hum Kinet 2013;36:119-26.
32. Maćkała K, Fostiak M.; Kowalski, K. Selected Determinants of Acceleration in the 100m Sprint. J Hum Kinet 2015;45:135-48.
33. Judge LW, Bellar D, Thrasher AB, Simon L, Hindawi OS, Wanless E. A pilot study exploring the quadratic nature of the relationship of strength to performance among shot putters. Technical Note. Int J Exerc Sci 2013;6(2): 171-9.
34. Terzis G, Spengos K, Karampatsos G, Manta P, Georgiadis G. Acute effect of drop jumping on throwing performance J Strength Cond Res 2009;23(9):2592-7.
35. Terzis G, Karampatsos G, Kyriazis T, Kavouras SA, Georgiadis G. Acute effects of countermovement jumping and sprinting on shot put performance. J Strength Cond Res 2012;26(3):684-90.
36. Evetovich TK, Conley DS, McCawley PF. Postactivation potentiation enhances upper- and lower-body athletic performance in collegiate male and female athletes. J Strength Cond Res 2015;29(2):336-42.
37. Kümmel J, Bergmann J, Prieske O, Kramer A, Granacher U, Gruber M. Effects of conditioning hops on drop jump and sprint performance: a randomized crossover pilot study in elite athletes. BMC Sports Sci Med Rehabil 2016;8(1):2-8.
38. Esformes JI, Cameron N, Bampouras TM. Postactivation potentiation following different modes of exercise. J Strength Cond Res 2010;24(7):1911-6.
39. Linder EE, Prins JH, Murata NM, Derenne C, Morgan CF, Solomon JR. Effects of preload 4 repetition maximum on 100-m sprint times in collegiate women. J Strength Cond Res 2010;24(5):1184-90.
40. Lim JJH, Kong PW. The application of postactivation potentiation on sprint performance. J Australian Strength Cond 2013;21(1): 61-66.

CORRESPONDING AUTHOR

Diego de Alcantara Borba
Rua Pérolas, 74, complemento, 205A, Santa Maria
Belo Horizonte, MG, Brasil.
CEP: 30525-500
Email: diegoalcantara1@gmail.com