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EFFECTS OF PLYOMETRIC EXERCISE ON POST-ACTIVATION POTENTIATION AND SPRINT PERFORMANCE

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This work is dedicated to my classmates and my dear parents.

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RESUMO

O aumento transitório no pico de torque de um *twitch* evocado eletricamente devido a uma contração muscular prévia é conhecido como potencialização pós-ativação (PPA). A ativação muscular prévia é conhecida como contração condicionante (CC) ou atividade condicionante (AC). AC pliométricas recentemente vem sendo utilizadas devido à facilidade de aplicação e efeitos positivos observados. É importante notar que enquanto a maioria dos estudos atribuem uma possível melhora no desempenho voluntário aos efeitos positivos da PPA, poucos deles realmente avaliaram se as propriedades contráteis estavam de fato potencializadas usando estimulação elétrica supramáxima concomitantemente à performance nos intervalos testados. Este trabalho foi dividido em dois estudos, cada um buscando responder se PPA pode aumentar o desempenho voluntário subsequente. No estudo um, foi realizada uma revisão sistemática acerca da temática, sendo analisados no total 19 artigos. Foram incluídos artigos originais e que usaram uma AC voluntária com confirmação de PPA por meio de uma resposta evocada (*twitch*) nos mesmos intervalos de recuperação na qual a performance voluntária foi mensurada. Artigos que não confirmaram PAP através de estímulo elétrico supramáximo foram excluídos, além de pesquisas com animais. Concluímos que PPA pode otimizar o desempenho voluntário quando sua magnitude é elevada. Porém, também observamos que desempenho otimizado esteve presente quando PPA estava ausente, demonstrando que outros fatores também são intervenientes, sendo que esses devem ser chamados de PAPE. No segundo estudo o objetivo do estudo foi analisar os efeitos de uma atividade condicionante (AC) pliométrica composta por séries múltiplas de saltos verticais na manifestação de PPA e na otimização da performance de *sprints.* Doze atletas da modalidade de atletismo de provas de velocidade, sendo 10 homens (23,5 ± 7,7 anos) e 2 mulheres (23,0 ± 2,82 anos) realizaram os procedimentos para determinar os efeitos da AC pliométrica em *sprints* de 30 metros ao longo de vários momentos após a AC (2 min, 4 min, 6 min, 8 min e 10 min). Também foi avaliado o pico de torque (Pt) no *twitch* visando determinar a magnitude de PPA e sua temporalidade após a AC. ANOVA de Modelo Misto com post-hoc de Bonferroni verificou que houve diferença entre pré e 2 min (p=0,01) e pré e 4min (p=0,02) na condição experimental para os tempos dos *sprints* de 30 metros. Com relação ao pico de torque no *twitch*, a análise de post-hoc apontou diferença significativa entre pré e 2min (p<0,01) e pré e 4min (p=0,02) demonstrando que o pico de torque (PPA) se manteve aumentado durante 4 minutos em relação ao pré nessa condição, com a magnitude de PPA observada de 17,04 ± 12,26% e 7,26 ± 8,89% para 2 min e 4 min, respectivamente. A inclusão da AC pliométrica na rotina de aquecimento otimizou a performance nos *sprints* de 30 metros nos intervalos de 2 min e 4 min após a AC. Nesses intervalos o fenômeno de PPA estava presente (confirmado através do pico de torque no *twitch*) possivelmente sendo interveniente nos aumentos de desempenho observados.

Palavras-chave: Performance voluntária, Potencialização pós-ativação, atividade condicionante

RESUMO EXPANDIDO

Introdução

Uma das consequências da ativação muscular prévia é uma resposta contrátil subsequente aumentada observada por meio de um estímulo elétrico. Esse aumento do torque subsequente é conhecido como potencialização pós-ativação (PPA). Outra consequência do histórico de contração é a fadiga, a qual afeta a *performance* negativamente. A ativação muscular prévia utilizada é conhecida como contração condicionante (CC) ou atividade condicionante (AC) Utilizar uma AC para desencadear PPA teoricamente pode levar a aumentos agudos na produção de potência e isso pode beneficiar a performance de atividades explosivas subsequentes. Um dos principais fenômenos que teoricamente podem estar atuando após AC e gerando aumentos da performance é o da PPA, cujo mecanismo fisiológico mais aceito é o da fosforilação da miosina regulatória de cadeia leve. A confirmação que esse mecanismo está presente é feito por meio de estímulo elétrico supra máximo *(twitchs)* e comparação do torque gerado para uma mesma intensidade de estímulo, antes e após a realização de uma AC. O desempenho humano pode ser afetado após um exercício tanto positivamente quanto negativamente, sendo assim, é de extrema importância que a rotina pré-competitiva seja perfeita, possibilitando que a performance máxima seja alcançada. Nessa perspectiva, pesquisas são conduzidas para encontrar uma AC ideal. Diversos estudos foram conduzidos ao longo dos anos testando diferentes protocolos de AC e seus efeitos na performance atlética posterior. Recentemente a utilização de AC pliométricas começou a ser estudada com resultados positivos sendo encontrados. Uma das grandes vantagens do uso desse tipo de atividade é a sua fácil inclusão nas rotinas de aquecimento e a ativação de múltiplos grupos musculares, além de não necessitar de um conjunto de habilidades específicas. Os protocolos de AC com cargas elevadas e isométricos máximos são pouco práticos antes de competições. Assim, protocolos de AC pliométricos que não necessitem de equipamentos sofisticados e que consigam ser facilmente realizados e tolerados pelos sujeitos durante os dias de competição, são muito mais atrativos. Poucos estudos testaram o efeito de AC pliométricas no desempenho de *sprints* subsequentes. O volume de atividade pode interferir na relação entre os mecanismos potencializadores e na fadiga gerada, afetando a magnitude das melhoras observadas. Já foi demonstrado que músculos com maior porcentagem de fibras tipo II podem apresentar maior nível de PPA. Assim, levando em conta que atletas de provas de potência apresentam maior concentração desse tipo de fibra, pode-se especular que atletas dessas modalidades consigam se beneficiar mais do uso de ACs. Séries múltiplas parecem ser mais eficientes para aumentos na performance atlética e que o intervalo ótimo após ACs. Diante do exposto, levando em conta a praticidade e possível efeitos positivos gerados devido a utilização de ACs pliométricas, bem como a relevância de uma possível melhora para a prática desportiva atual de alto nível, onde pequenas mudanças são de extrema importância formulou-se a seguinte questão problema: "Será que séries múltiplas de atividades pliométricas são eficazes em desencadear aumentos da performance de *sprints*? "

Objetivos

O objetivo geral foi analisar os efeitos de uma AC pliométrica na otimização da performance de *sprints.* Os objetivos específicos foram: analisar o pico de torque no *twitch* antes e após a realização de uma AC pliométrica (PPA); analisar a taxa de desenvolvimento de torque no *twitch* antes e após a realização de uma AC pliométrica; e verificar associações entre mudanças no pico de torque e taxa de desenvolvimento de torque no *twitch* (PPA) com mudanças na performance de *sprints* de 30 metros.

Metodologia

O estudo foi de caráter experimental por contar com avaliações antes e após a aplicação de um tratamento (AC pliométrica). A AC pliométrica foi constituída por 3 séries de 5 saltos verticais máximos separados por 1 min de intervalo entre cada série. Foram utilizados um grupo controle e um grupo experimental para verificar efeito do tratamento na performance voluntária de *sprints* e contrações explosivas. Os mesmos sujeitos realizaram as duas condições, caracterizando o design "within subject" onde os mesmos sujeitos realizam todas as condições. O estudo será conduzido em três momentos distintos (M1, M2) para contemplar os seguintes objetivos: M1) analisar os efeitos da AC pliométrica (variável independente) no tempo de *sprints* de 30 metros (variável dependente) ao longo de vários momentos na recuperação (2 min, 4 min, 6 min, 8 min e 10 min); M2) analisar se a AC pliométrica induz PPA, através da variação do pico de torque em um *twitch* (variável dependente) antes e após a realização da AC.

Resultados e Discussão

Para o pico de torque houve interação entre grupo e tempo ($p<0,01$) indicando que os efeitos no tempo foram diferentes entre as condições. No grupo controle não houve diferença entre nenhum intervalo de tempo ($p>0.05$) em relação ao pré. No grupo experimental a análise de post-hoc verificou diferença significativa entre pré e 2 min ($p<0.01$), pré e 4min ($p=0.02$) demonstrando que o pico de torque se manteve aumentado durante 4 minutos em relação ao pré nessa condição. Não houve diferença entre pré e 6 min ($p=0.55$), pré e 8 min ($p=1.00$) e pré e 10min ($p=1.00$) demonstrado que nesses intervalos os valores já voltaram aos valores iniciais. Não foram encontradas diferenças entre os grupos (controle e experimental) para nenhum dos intervalos de tempo testados ($p>0.05$). Para o grupo experimental a magnitude de PPA foi de 17.04±12.26%, 7.26±8.89%, 3.68±7.38%, 1.11±6.70% e 0.01±7.10% nos intervalos de 2 min, 4 min, 6 min, 8 min, 10 min, respectivamente. Pode-se observar que no grupo controle os valores se mantiveram estáveis com leve diminuição ao longo do tempo. Para os *sprints* de 10 metros houve interação entre grupo e tempo ($p=0.01$). A análise post-hoc verificou que houve diferença entre o tempo 4 min e 10 min na condição experimental, indicando que os tempos foram diminuindo ao longo do tempo nesse intervalo. Não houve diferença entre pré com nenhum intervalo testado após a AC para os *sprints* de 10 metros ($p>0.05$). Não foram encontradas diferenças em nenhum intervalo de tempo na condição controle. Para a os *sprints* de 30 metros houve interação entre grupo e tempo ($p<0.01$) A análise post-hoc verificou que houve diferença entre pré e 2 min ($p= 0.01$) e pré e 4min ($p= 0.02$) na condição experimental indicando que o tempo melhorou nesses intervalos em comparação ao tempo antes da AC. Na condição controle não foram encontradas diferenças significativas para nenhum intervalo.

Considerações Finais

Conclui-se com o primeiro estudo que apenas a presença de PPA não garante desempenho voluntário otimizado. Os resultados mostraram que PPA otimizou o desempenho voluntário apenas quando sua magnitude atingiu valores extremos. Além disso, foram encontrados estudos em que o desempenho foi otimizado quando o PPA não estava presente, demonstrando que os mecanismos do PAPE também podem melhorar o desempenho, mesmo sem PPA no momento em que a atividade principal foi testada. Isso mostra que a fosforilação da miosina regulatória de cadeia leve e o aumento observado no torque de uma contração, após uma AC, se traduz apenas na otimização do desempenho voluntário em alguns casos específicos, como quando a magnitude do PPA é extremamente alta. Portanto, isso demonstra que deve-se tomar cuidado ao relacionar o fenômeno PPA ao aumento voluntário do desempenho sem a sua correta mensuração por meio de estimulação elétrica. Não é adequado supor que um músculo que demonstre PPA tenha um desempenho voluntário superior, porque isso nem sempre é

observado. Conclui-se também que atividades pliométricas prévias aprimora a função muscular (PPA) e permite melhora aguda do desempenho de *sprin*ts (PAPE). O uso de 3 séries de 5 saltos verticais como AC melhorou em aproximadamente 2-3% o desempenho subsequente de 30 metros em intervalos de recuperação de 2 e 4 minutos. A confirmação da PPA por meio de estimulação elétrica nos mesmos intervalos de recuperação também foi verificada e esses resultados sugerem que o aprimoramento do desempenho do *sprint* pode estar parcialmente relacionado à PPA, pois foram encontradas melhoras de desempenho apenas nos mesmos intervalos de recuperação em que a PPA estava presente. No presente estudo, PPA durou apenas 4 minutos, após os quais a melhoria de desempenho sugerida (PAPE) devido a esse fenômeno é perdida. No entanto, é importante levar em consideração que não há relação de causa e efeito e que outros mecanismos do PAPE também podem estar envolvidos no desempenho otimizado dos *sprints.*

Palavras-chave: Performance voluntária, Potencialização pós-ativação, atividade condicionante

ABSTRACT

The transient increase in peak torque of an electrically evoked twitch due to prior muscle contraction is known as post-activation potentiation (PAP). Prior muscle activation is known as conditioning contraction (CC) or conditioning activity (AC). Plyometric CA has recently been used due to its ease of application and positive effects observed. It is important to note that while most studies attribute a possible improvement in voluntary performance to the positive effects of PAP, few studies have really evaluated whether contractile properties were actually enhanced using supra-maximal electrical stimulation concomitantly with performance at the intervals tested. This work was divided into two studies, each seeking to answer a specific question. In the study one, a systematic review was performed, and a total of 19 articles were analyzed aiming to investigate if PAP could improve subsequent voluntary performance. Original articles that used a voluntary CA and confirmed PAP through a twitch response at the same recovery intervals where voluntary performance was measured were included. Articles that did not confirm PAP by supramaximal electrical stimulation were excluded, in addition to animal research. We conclude that PAP can optimize voluntary performance when its magnitude is high. However, we also observed that optimized performance was present when PAP was absent, demonstrating that other factors are also intervening, and these should be called PAPE. In the second study, the objective was to analyze the effects of a plyometric conditioning activity (CA) composed of multiple series of vertical jumps on PAP manifestation and sprint performance optimization. Twelve sprint athletes, 10 men (23.5 ± 7.7 years) and 2 women (23.0 ± 2.82 years) performed the procedures to determine the effects of plyometric CA on sprints of 30 meters over several recovery intervals after to CA (2, 4, 6, 8 and 10 min). We also evaluated the peak torque (Pt) to determine the magnitude of PAP and its time-course after CA. Mixed-model ANOVA with Bonferroni post-hoc verified that there was a difference between pre and 2min ($p = 0.01$) and pre and 4min ($p = 0.02$) in the experimental condition for 30 m sprint times. Regarding the peak torque in the twitch, the post hoc analysis showed significant difference between pre and 2min ($p <0.01$) and pre and 4min ($p = 0.02$) showing that the peak torque (PAP) remained increased during 4 minutes compared to the pre in this condition, with the observed PAP magnitude of 17.04 ± 12.26% and 7.26 ± 8.89% for 2 min and 4 min, respectively. As conclusion, the inclusion of plyometric CA in the warm-up routine optimized performance in 30-m sprints at 2 min and 4 min intervals after the CA. At these intervals the PAP phenomenon was present (confirmed through twitch peak torque) possibly being intervening in the observed performance increases.

Keywords: Voluntary performance, postactivation potentiation, myosin light chains, performance enhancement, conditioning contraction, twitch.

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PAP – Post-activation potentiation

PAPE – Post-Activation performance enhancement

CC – Conditioning contraction

CA – Conditioning activity

MVC – Maximal voluntary contraction

SJ – *Squat jump*

EMG – Electromyography

CMJ – *Countermovement jump*

DJ – *Drop jump*

RFD– Rate of force development

Pt – Peak Torque

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CHAPTER ONE
1 INTRODUCTION

1.1 POST-ACTIVATION POTENTIATION AND VOLUNTARY PERFORMANCE

It is well known that contraction history partially determines skeletal muscle contractile responses (SALE, 2002). One of the consequences of contraction history is fatigue (SARGEANT, 2007), which negatively affects performance (MACINTOSH; SHAHI 2011). Another consequence of contraction history, i.e., previous muscle activation, is an increased subsequent contractile response (MACINTOSH et al. 2012). When previous contraction originates from a voluntary activation, the subsequent increase of a contractile response for a known activation is referred to as post-activation potentiation (PAP). The balance between PAP and fatigue will dictate whether subsequent performance will increase or decrease. The previous muscle activation is referred to as conditioning contraction (CC) or conditioning activity (CA) (TILLIN; BISHOP, 2009).

The first studies referred PAP as an increased response to a supra-maximal single electrical stimulus (twitch) performed on the motor nerve or directly on the muscle after performing a muscle contraction (MACINTOSH; ROBILLARD; TOMARAS, 2012). Thus, the term PAP was inserted in the context of isolated contractile properties (BURKE; RUDOMIN; ZAJAC, 1976; VANDERVOORT; QUINLAN; MCCOMAS, 1983) described as the increase in torque of an electrically evoked twitch (BAUDRY; DUCHATEAU, 2007b; HAMADA et al., 2000; MIYAMOTO et al., 2010; SALE, 2002; VANDERVOORT; QUINLAN; MCCOMAS, 1983). The primary mechanism related to PAP is myosin regulatory light chain phosphorylation (RLC), which increases the sensitivity of the contractile apparatus to calcium (VANDENBOOM, 2017). The first study that demonstrated this correlation between myosin RLC phosphorylation and increased twitch torque was the study of Manning and Stull (1979).

With the beginning of studies involving voluntary activities, the term PAP was also used to describe increased performance; however, according to Cuenca-Fernandes et al. (2017), inaccurately, since these studies did not measure isolated contractile properties, but performance in a voluntary complex activity. The main problem is the influence of several factors unrelated to myosin RLC phosphorylation, such as: temperature increases (BISHOP, 2003) increased excitability of motoneurons (FOLLAND et al. 2008), increased recruitment of motor units (TILLIN; BISHOP, 2009), acute elevations in plasma catecholamines levels (CAIRNS; BORRANI 2015), increases in the circulating concentration of testosterone after exercise (CREWTHER et al. 2011), learning effect and familiarization with the main task (MACINTOSH et al. 2012), placebo effect and subject motivation (BEEDIE; FOAD, 2009). Additionally, care must be taken when analyzing studies inferring participation of the PAP phenomenon when voluntary performance is accessed without information about contractile properties evaluated through electrical stimulation. In these cases, it is possible only speculate that there was indeed PAP (DOCHERTY; HODGSON, 2007). Some authors even suggest the term post-activation performance enhancement (PAPE) (CUENCA-FERNÁNDEZ et al., 2017) to refer to these cases. This enhanced performance may be influenced in part by PAP, as well as by any other mechanisms mentioned above.

Since PAP phenomenon can acutely optimize the contractile function, confirmed by studies with electrical stimulation, the scientific community has shown considerable interest in its applicability on sport performance. Sale (2002), therefore, suggested that theoretically, PAP could be used as part of a warm-up routine, in preparation for a high intensity performance. This speculation set off a series of research studies aiming to test if conditioning contractions, that would be expected to elicit PAP, could enhance subsequent performance. In this sense, the inclusion of a CA as part of warm-up has been widely studied in the literature; thus, researchers seek to identify a stimulus that can acutely improve performance (SUCHOMEL; LAMONT; MOIR, 2016).

However, there is a wide range in the magnitude of related increases and the time course that the increases occur, depending on how performance is evaluated (CUENCA-FERNÁNDEZ et al., 2017). Studies analyzing the contractile response through electrical stimulation showed substantial improvements in twitch torque immediately after a contraction (BAUDRY; DUCHATEAU, 2007a, 2007b). However, positive increases in voluntary performance seems to occur at longer and more distinct intervals, between 5 and 12 min (SEITZ; HAFF, 2016; WILSON et al., 2013), at a time when the potentiation of contractile properties is very small or even absent. Thus, it is important to monitor the contractile properties to know if, when the main activity is tested, the optimized state is still present.

In summary, each myosin RLC has a specific site for incorporation of a phosphate molecule (TILLIN; BISHOP, 2009) and this incorporation occurs when a muscle contraction is initiated. The more intense the contraction, the more fibers are recruited and the higher the phosphorylation level, which optimize the interaction between contractile proteins. During the time the phosphate molecule is incorporated, the torque of a twitch is increased (MANNING;

STULL, 1979) possibly optimizing subsequent voluntary performance (PAPE). However, if the purpose is to investigate if PAP phenomena contribute in performance improvements, only studies that confirmed the increase in twitch torque at the time that PAPE was measured should be analyzed.

1.2 THE USE OF PLYOMETRIC EXERCISES AS CA FOR INDUCING PAP AND PAPE

The type of exercise used as CA, mainly regarding the specificity of its muscular action, is a factor that play an important role in modulating the effects of potentiation in voluntary activities (FRENCH; KRAEMER; COOKE, 2003). The efficiency of previous activity is known to be related to the duration of its potentiating effect, which is closely connected with the practical implications (BATISTA et al., 2007).

Numerous physical exercises have been tested as CA, ranging from general strength exercises, vertical jumps, sprints, among other possibilities. In general, it has been advocated that the conditioning exercise used should match the motor pattern of subsequent performance movement, thus following the principle of specificity (GARCIA et al., 2020). In this context, it is proposed that dynamic sportive activities in their nature should be preceded by dynamic CAs (GUGGENHEIMER et al., 2009). Fletcher (2013) states, for example, if the main task includes the stretching-shortening cycle (CAE), which is a type of muscle action that occurs in most sports activities, CA should also have a similar pattern.

Several studies have been conducted over the years testing different CA protocols and their effects on athletic performance (TILLIN; BISHOP, 2009). Most studies have used maximal voluntary contractions (BABAULT et al. 2008; BATISTA et al., 2011; BAUDRY; DUCHATEAU, 2007; BAUDRY et al. 2008) or high intensity dynamic strength exercises as CA (BATISTA ET AL., 2007; BEVAN ET AL., 2010; CHATZOPOULOS ET AL., 2007; CHIU ET AL., 2003; BOULLOSA ET AL., 2013; CREWTHER et al., 2011). However, this type of CA presents lack of specificity and is not easy to perform without specific equipment, limiting their use before competitions. For this reason, plyometric CA protocols emerge as an attractive alternative; plyometrics can be easily performed by athletes just prior to their competition (TURNER et al. 2015). Any sport activity that involves high running speeds could benefit from this type of protocol. In addition, plyometric exercises can be designed to be more specific in terms of the muscle contraction seem during the competition (i.e., stretch-shortening cycle) (FLETCHER 2013). This allow the neural drive can propagate along the same pathways

(BATISTA et al., 2011) and allows the fibers to be phosphorylated (FUKUTANI et al., 2014a) benefiting from intramuscular and neural mechanisms related to increased performance in voluntary activities. It is also described that distinct muscle actions trigger different levels of PAP in the activity to be performed (BOGDANIS et al., 2014).

In this perspective, some researches have been conducted seeking an ideal conditioning activity to induce increases in sport performance (BATISTA et al., 2007). Previous research using plyometric exercise as CA have found positive results on the performance of drop jumps (BERGMANN et al. 2013), vertical jumps (BRIDGEMAN ET AL. 2016; CHEN et al. 2013), and long jump (BOGDANIS et al 2017). However, few studies have tested the effect of plyometric CAs on sprint performance, that is a more complex sportive motor task. Sprints are activities in which athletes require high muscular power levels (CHATZOPOULOS ET AL., 2007); thus, the use of CA for improvement of lower limb muscle power is a permanent concern of power-velocity field athletes.

It is known that the volume and intensity of a CA directly affect the levels of PAP and fatigue generated, and they are connected with the manifestation of observed effects (TILLIN; BISHOP, 2009). Till and Cooke (2009) found that a single set of 5 vertical jumps did not optimize a subsequent 10 and 20 m sprint performance in soccer players. Recent metanalysis showed that multiple sets appear to be more efficient in increasing athletic performance (SEITZ; HAFF, 2016; WILSON et al., 2013), suggesting that 1 set of 5 vertical jumps is not sufficient (low volume) to trigger positive effects on sprint performance. High volume CAs require longer recovery periods for positive effects to be demonstrated and for fatigue to decrease (BATISTA et al., 2007; CRUM et al., 2012; NACLERIO et al., 2015). Thus, the time after conditioning activity needs to be adjusted (BEVAN et al., 2010; GOŁAS et al., 2016; MCCANN; FLANAGAN, 2010; NACLERIO et al., 2014, 2015), because if it is too short, fatigue prevents performance improvements and if it is too long, the potentialized state will be lost (CHEN et al., 2013; CRUM et al., 2012; FLETCHER, 2013). Conflicting responses after plyometric CA on athletic performance have been attributed to the different CA used, as well as the difference in intensity, volume, and recovery period used (TILLIN; BISHOP, 2009).

The individuals' training level also seems to influence the manifestation of the positive effects of CAs (BERNING et al., 2010; CHIU et al., 2003), possibly due to the increased strength level increasing with the training time, which may influence the relationship between potentiation and fatigue (KILDUFF et al., 2007). Theoretically, athletes with higher training and strength may also have less fatigue after performing a CA compared to sedentary (CHIU et al., 2003), obtaining greater advantage. Indeed, the potential benefits that these acute increases in performance bring are most interesting especially for elite athletes (FRENCH; KRAEMER; COOKE, 2003), due to the similar level of performance and training among them. In some studies, performance improvement is only observed after previous protocols when subjects are separated into groups differentiated by strength level (BEVAN et al., 2010; CHIU et al., 2003). In the same way, the effectiveness of previous protocols is highly dependent on the modality practiced by the athlete performing the activity and on the subject's characteristics (EVETOVICH; CONLEY; MCCAWLEY, 2015; SUCHOMEL; LAMONT; MOIR, 2016). It has been shown that muscles with a higher percentage of type II fibers may demonstrate higher PAP (HAMADA et al., 2000). Thus, considering that elite sprinters have higher percentage of type II fibers, it can be speculated that athletes with these capabilities can benefit more from the use of CA.

In summary, in order to complement the available literature, it is necessary to evaluate the effect of multiple sets of a plyometric CA on sprint performance optimization at different rest intervals after the CA in elite sprinters. There is no data in the literature confirming whether plyometric CAs are effective to induce PAP, and that it can improve performance (PAPE) in this population. Also, to confirm PAP presence, it is necessary to evaluate contractile properties through electrical stimulation after the CA.

It is important to emphasize that most of the recent studies in the literature, that mention PAP, did not confirm PAP, leaving doubt if an enhanced contractile response was present when performance test was measured. In this case, other mechanism may have caused the improvements. Analyzing contractile properties will better clarify the role of PAP and the related possible acute changes on voluntary performance associated with it. It is noteworthy that no study has confirmed PAP in the quadriceps muscles after vertical jumps as plyometric CA and it is not known whether the magnitude of PAP after this type of CA may be related to subsequent performance increases (PAPE).

1.3 OBJECTIVES

1.3.1 **Main objective**

To verify the effect of a plyometric CA on post activation potentiation and on voluntary performance.

1.3.2 **Specific objectives**

1.3.2.1 Study 1

To investigate if increases in voluntary performance after a conditioning activity (CA) are related to the PAP phenomenon.

1.3.2.2 Study 2

To analyze the effects of a plyometric CA composed by multiple sets of vertical jumps on PAP and on 30m sprint performance over different recovery intervals.

1.4 HIPOTHESIS

1.4.1.1 Hypothesis Study 1

H1: Induced PAP by the CC positively affects voluntary performance.

1.4.1.2 Hypothesis Study 2

H1: Plyometric CA will induce PAP in the quadriceps muscles.

H2: Induced PAP will positively affect sprint performance.

CHAPTER TWO

2 STUDY ONE: DOES POST-ACTIVATION POTENTIATION (PAP) INCREASE VOLUNTARY PERFORMANCE?

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Systematic Review

DOES POST-ACTIVATION POTENTIATION (PAP) INCREASE VOLUNTARY PERFORMANCE?

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Abstract

The transient increase in torque of an electrically evoked twitch following a voluntary muscle contraction is called postactivation potentiation (PAP). Phosphorylation of myosin regulatory light chains is the most accepted mechanism explaining the enhanced electrically evoked twitch torque. While many authors attribute voluntary performance improvement after a conditioning contraction (PAPE) to the positive effects of PAP, few actually confirmed that contraction was indeed potentiated using electrical stimulation (twitch response) at the time that PAPE was measured. Thus, this review aims to investigate if increases in voluntary performance after a conditioning contraction (CC) are related to the PAP phenomenon. For this, studies that confirmed the presence of PAP through an evoked response after a voluntary CC and concurrently evaluated PAPE were reviewed. Some studies reported increases in PAPE when PAP reaches extremely high values. However, PAPE has also been reported when PAP was not present, and unchanged/diminished performance has been identified when PAP was present. This range of observations demonstrates that mechanisms of PAPE are different

from mechanisms of PAP. These mechanisms of PAPE still need to be understood and those studying PAPE should not assume that regulatory light chain phosphorylation is the mechanism for such enhanced voluntary performance.

Novelty:

- The occurrence of PAP does not necessarily mean that the voluntary performance will be improved.
- Improvement in voluntary performance is sometimes observed when the PAP level reaches extremely high values, but may occur when PAP is absent.
- Other mechanisms may be more relevant than that for PAP in the manifestation of acute increases in performance following a conditioning contraction.

Keywords: Voluntary performance, postactivation potentiation, myosin light chains, performance enhancemet, conditioning contraction, twitch.

2.1 INTRODUCTION

The contraction history partially determines skeletal muscle contractile responses (Sale 2002, 2004; Hodgson et al. 2005). One of the consequences of contraction history is fatigue, leading to reduction in strength, speed, work and muscle power (Sargeant 2007), which negatively affects performance (Sale 2002; MacIntosh and Shahi 2011). Another consequence of contraction history, i.e., previous muscle activation, is an increased subsequent contractile response for a known activation, commonly evaluated with electrical stimulation (MacIntosh and Willis 2000; MacIntosh et al. 2012). When previous contraction originates from a voluntary activation, the subsequent increase of a contractile response for a known activation is referred to as post-activation potentiation (PAP). Alternatively, when previous contraction originates from an electrically evoked contraction the subsequent increase of contractile response has been called posttetanic potentiation (PTP) (MacIntosh 2010). The previous muscle activation is referred to as conditioning contraction (CC) (Tillin and Bishop 2009; MacIntosh et al. 2012). The effect of previous muscle contraction on subsequent torque increase of evoked responses has already been documented, mainly with studies involving animals (Brown and Tuttle 1926; Brown and von Euler 1938). The main accepted mechanism associated with increased torque due to prior activation is phosphorylation of the myosin regulatory light chains (RLC) (Manning and Stull 1979; Vandenboom et al. 1993; Grange et al. 1993), which increases calcium sensitivity of the contractile apparatus (Persechini, Stull and Cooke 1985; Vandenboom 2017), enhancing the interaction between actin and myosin in the active muscle (Sweeney and Stull 1990).

Although PAP does not increase maximal force, it does increase the rate of force development, even with maximal effort. Sale (2002) suggested that theoretically, PAP could be used as part of a warm-up routine, in preparation for a high intensity performance because it should be expected to increase peak force when contraction duration was short. This speculation set off a series of research studies to see if conditioning contractions that would be expected to elicit PAP could enhance subsequent performance of brief maximal effort movements. It should be pointed out, however, that enhanced voluntary performance after a high intensity conditioning contraction can occur by several mechanisms, not just the mechanism known to be associated with PAP.

This notion that PAP could be part of a warm-up has created confusion in the literature. The term PAP has been used in several studies where presence of PAP has not been confirmed with evoked responses and probably was not present (MacIntosh et al. 2012). This confusion was pointed out by Cuenca-Fernandez et al. (2017). Several studies have been completed putatively evaluating the apparent role of PAP in enhancing voluntary performance, without confirming that potentiation of the contractile properties was present by using supra maximal stimulation. The design of these studies has typically involved the following sequence: performance test, conditioning contraction, wait, performance test. The second performance test is often a better performance than the first and the authors assume that PAP caused the improvement, even when the wait was sufficient to allow full dephosphorylation of the regulatory light chains of myosin. Cuenca-Fernandez et al. (2017) demonstrated that a second performance test is improved relative to a first performance test, even when no conditioning contraction was permitted. This observation would indicate that mechanisms other than PAP contribute to this improved performance. Several factors unrelated to the phosphorylation of the myosin RLC, but considered part of warm-up, could contribute to improved voluntary performance. These alternative mechanisms include: temperature increases (Bishop 2003; McGowan et al. 2015; Silva et al. 2018), increased excitability of motoneurons (Folland et al. 2008), increased recruitment of motor units (Tillin and Bishop 2009), acute elevations in plasma catecholamines levels (Cairns and Borrani 2015), increases in the circulating concentration of testosterone after exercise (Crewther et al. 2011), learning effect and familiarization with the main task (MacIntosh et al. 2012), placebo effect and subject motivation (Beedie and Foad 2009). In these cases, it is practically impossible to determine the contribution of each of these potential factors to the performance of the second performance test.

Based on these observations, Cuenca-Fernández et al. (2017) have suggested the term post-activation performance enhancement (PAPE) be used to reflect an increase in performance of a task, following a voluntary contraction. This enhanced performance may be influenced in part by PAP, as well as by any other mechanisms mentioned above. Thus, it is important to emphasize that care should be taken when interpreting studies inferring participation of the PAP phenomenon when the voluntary performance is assessed without information about the contractile properties through an electrically evoked response. When contractile properties are not assessed, one can only speculate that PAP was present and was a contributing factor in the results when performance was accomplished at a time when light chain phosphorylation should be present, as suggested by many authors (Rassier et al. 1999; MacIntosh 2010; Tomaras and MacIntosh 2011;

MacIntosh et al. 2012; Fukutani et al. 2014b; Gago et al. 2014). Moreover, even when PAP has been confirmed to exist at the time of the improved performance, the above list of alternative mechanisms cannot be simply discarded; the actual role of this "artificially observed" torque increase in voluntary performance has not yet been fully clarified (Vandenboom 2017).

Thus, this review aims to investigate if increases in voluntary performance after a CC are related to the PAP phenomenon. For this, studies that confirmed the presence of PAP through an evoked (brief supra maximal stimulation) response after a voluntary CC and occurred at the same time as a subsequent voluntary performance will be evaluated. These two independent measures would ensure that the muscle was indeed potentiated at the specific time when the performance was tested. In addition, the possible physiological mechanisms involved will also be discussed. Most of the recent studies in the literature, that mention PAP, did not confirm PAP, leaving doubt if an enhanced contractile response was present when the second performance test was measured. In this case, other mechanism may have caused the improvements. This review will better clarify the role of PAP and the related possible acute changes on voluntary performance associated with it.

2.2 METHODOLOGICAL PROCEDURES

An electronic search was conducted to identify relevant scientific articles for the purpose of this review, using PubMed and Scopus databases with the following descriptors: postactivation potentiation, "PAP", twitch and performance. Two-hundred seventy eight articles were initially found. After deletion of the duplicate articles, there were 243 articles remaining. The individual analysis of the title and the abstracts of the articles allowed the application of the inclusion and exclusion criteria (Figure 1). After reading the titles and abstracts, 137 articles were selected. These were the articles that involved measurement of PAP and voluntary performance in humans. Then, after a detailed reading of the complete articles, 19 articles were included in the results table. As criteria to be included they had to be original human subject investigations, use a voluntary CC with confirmation of PAP through an evoked response with supra maximal stimulation at the same recovery interval that the second voluntary performance was measured. Articles that did not confirm PAP through supra maximal electrical stimulation or were performed in animals were excluded. The flow diagram (Figure 1) shows the screening processes.

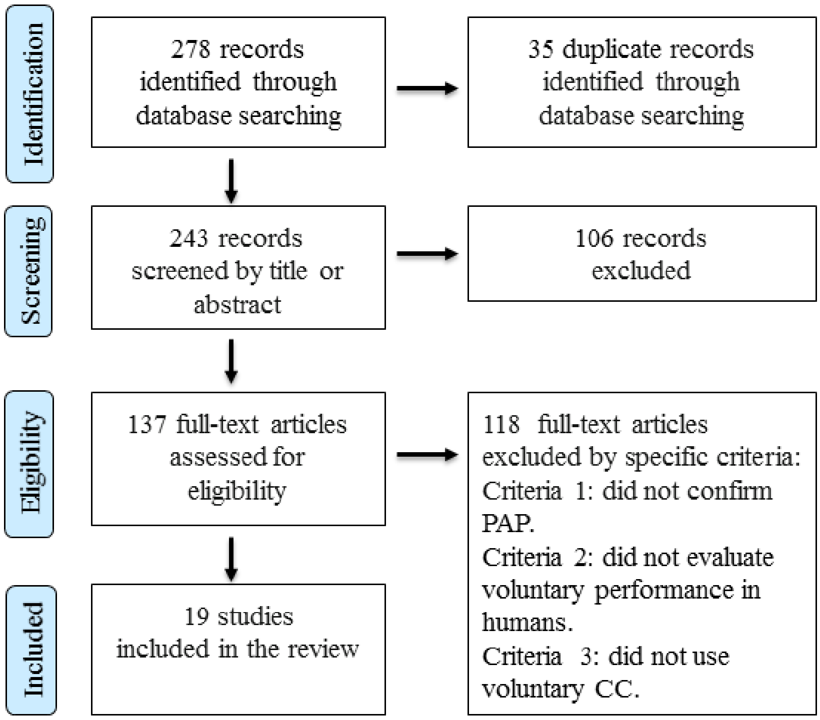

Figure 1. PRISMA flow diagram: studies that underwent the review process.

2.3 RESULTS

Table 1 presents details of methods and main results of the 19 studies included in this review that analyzed voluntary performance with confirmation of PAP.

Table 1. Overview of studies that analyzed voluntary performance with confirmation of PAP.

Study	N	Conditioning Contraction	Volume	Rest Interval	Measurements/Design	Main results
Baudry and Duchateau (2007a)	10	MVC of thumb adductor	6 s	5 s, 1, 2, 3, 4, 5 & 10 min	Twitch, high frequency stimulation (or voluntary isometric ballistic contractions), CC	↑ Twitch RFD for 10 min ↑ High frequency stimulation RFD for 5 min ↑ Voluntary isometric ballistic contractions RFD for 2min
Baudry and Duchateau (2007b)	10	MVC of thumb adductor	6 s	5 s, 1, 2, 3, 4, 5 &10 min	Twitch, high frequency stimulation (or voluntary dynamic ballistic contractions), CC	↑ Twitch angular velocity for 10min ↑ High frequency stimulation angular velocity for 4-5min ↑ Voluntary dynamic ballistic contractions angular velocity for 4-5min
Bergmann et al. (2013)	12	Maximal two-legged hops	10	30 s - 5 min	Twitch, CC, twitch; Drop jump, CC, drop jump	↑ Twitch for 5min ↑ Drop jump
Fukutani et al. (2012)	12	MVC of plantar flexors	6 s at 40, 60, 80 & 100% of MVC	Immediately after	Twitch; voluntary isokinetic torque, CC, twitch, voluntary isokinetic torque	↑ Twitch ↑ Dynamic voluntary concentric torque only in condition 80 and 100% MVC.
Fukutani et al. (2013)	12	MVC of plantar flexors	6 s	3 s, 1 & 5 min	Twitch, dynamic torque at 30°/s and 180 °/s, CC, twitch, dynamic concentric torque at 30°/s and 180 °/s	↑ Dynamic concentric torque at 180 °/s
Fukutani et al. (2014b)	8	Squat	5 reps at 45 %, 5 reps at 60 %, 3 reps at 75 % & 3 reps at 90%; 5 reps at 45 %, 5 reps at 60 % & 3 reps at 75 %.	30 s & 1 min	Twitch, CMJ, CC, twitch, CMJ	↑ Twitch ↑ CMJ

Folland et al. (2008)	8	MVC of knee extensors	10 s	0.10, 0.25, 0.40, 2, 2.30, 4, 4.30, 6, 8, 10,14 &18 min	Twitch, CC, twitch, H-reflex; Voluntary performances, CC, voluntary performances	↑ H-reflex for 5-11 min ↑ Twitch for 18 min ↔ Voluntary performance unchanged
Gago et al. (2018)	9	MVC of plantar flexor	6 s	0.5, 1.5, 3, 6 &15min	Voluntary concentric contraction, CC, voluntary concentric contraction; Twitch, CC, twitch	↑ Twitch for 8min ↑ Dynamic peak concentric torque between 1.5-5 min ↑ Dynamic concentric RFD between 1.5-5 min
Gossen and Sale (2000)	10	MVC of knee extensors	10 s	15 s	Twitch, CC, twitch, dynamic knee extension	↑Twitch ↔ Peak velocity and power
Hodgson et al. (2008)	13	MVC of plantar flexors	3 x 5 s	Immediately after. Every 30 sec for 11 min	Twitch, H-reflex, isometric plantar flexion, CC, twitch, H-reflex, isometric plantar flexion	↑ Twitch for 1min ↔ H-reflex ↔Isometric voluntary peak torque ↔ Isometric RFD
Mitchell and Sale (2011)	11	Squat	5 RM	4 min	Twitch ,CMJ, CC, twitch, CMJ	↑ Twitch ↑CMJ
Miyamoto et al. (2011)	9	MVC of plantar flexors	6 s	5 s, 1, 2, 3, 4, 5 & 10 min	Twitch, voluntary isokinetic torque, CC, twitch, voluntary isokinetic	↑ Twitch for 10 min ↑ Dynamic voluntary isokinetic torque between 1-3 min
Miyamoto et al. (2012)	13	MVC of knee extensors	3, 5 & 10s voluntary 5 s tetanic (20hz)	1, 3 & 5 min	Twitch, voluntary isokinetic torque, CC, twitch, voluntary isokinetic torque	↑ Twitch ↑ Dynamic voluntary isokinetic torque between 1-3 min
Nibali et al. (2013)	8	Squat	5 RM	4, 8 &12 min	Twitch, SJ, CC, twitch, SJ	↑ Twitch ↔ Performance did not follow PAP variation

Pearson and Hussain (2014)	8	Isometric Squat	3, 5 e 7 s	4 min	CMJ, twitch, CC, CMJ, twitch	↔ Twitch ↔ CMJ
Prieske et al. (2018)	12	Leg press/Double-leg stances on a balance board	3x 8-10 reps	7 min	Twitch, MVC, twitch, CMJ, DJ, CC, MVC, twitch, CMJ, DJ	↑ Twitch ↔ Performance
Seitz et al. (2015)	17	Isokinetic knee extensions	4 knee extensions at 60°/s, 4 and 12 at 180°/s, and 4 and 20 at 300°/s	1, 4, 7, 10, &13 min	Twitch, dynamic knee extensions, CC, twitch, dynamic knee extensions	↑ Twitch ↑ Voluntary torque at 4min and 7min
Smith et al.(2014)	11	MVC and tetanic (50Hz) of tibialis anterior tibial	10 s	Immediately after	Twitch, CC, twitch, isometric voluntary ballistic contractions	↑ Twitch ↓ Isometric voluntary ballistic RFD
Thomas et al. (2017)	11	Squat	3x3 a 80%, 90% & 100% RM	8 min	Twitch, CMJ, CC, CMJ twitch.	↑ CMJ ↓ Twitch

CMJ – Counter movement jump, **MVC** – Maximal voluntary contraction, **DJ** – Drop jump, **SJ** – Squat jump, **RFD** – Rate of force development; **RM** –repetition-maximum

2.4 DISCUSSION

2.4.1 **The role of PAP in voluntary performance**

There are many studies that attribute a possible voluntary performance improvement to the positive effects of PAP, but few of them actually measured whether contractile properties were indeed potentiated using supramaximal electrical stimulation (twitch response) at the same recovery intervals that voluntary performance was measured. Performance enhancement associated with prior voluntary conditioning contraction should be referred to as PAPE, and the mechanism can be considered unknown, unless PAP is confirmed to coexist with PAPE. In this review, we analyzed only studies that confirmed PAP, avoiding those articles where PAP was simply assumed. We verified that all studies reported contractile response improvements immediately after a CC, however, only in some specific cases were these improvements observed in the contractile properties associated with a concurrent improved voluntary performance. It was also observed in some studies that improvements of performance (PAPE) occurred at times for which PAP was not present, suggesting that factors other than PAP contribute to acutely enhance voluntary performance after a CC.

There is a large difference in the magnitude of increase of a twitch (which represents the most sensitive contractile response) and the increase in voluntary performance after a CC (Cuenca-Fernández et al. 2017). The torque increase in the twitch observed with electrical stimulation is maximal immediately after a CC, with values approaching 200% (depending on the muscle evaluated) and torque falls exponentially over time, approaching the pre CC value within a few minutes (Baudry and Duchateau 2004). Increases in voluntary performance usually occur at longer and distinct intervals, generally from 5 to 12 min (Wilson et al. 2013; Seitz and Haff 2016) at a time when PAP has already decreased dramatically, or is absent. Thus, it is possible that most of the studies in the literature that did not evaluate the contractile properties for confirmation of PAP have incorrectly attributed the improved voluntary performance to PAP. Furthermore, even in studies in which PAP was confirmed, it is still not possible to guarantee that in fact the increased performance was due to PAP or some other mechanism not yet known.

Baudry and Duchateau (2007a) were the first authors to report improvements in voluntary performance of thumb adductors (9-24%) after a CC with confirmation of PAP through supra maximal electrical stimulation at the specific time points where performance was evaluated. However, the time-course and magnitude of the responses differed considerably. The increase in RFD in the twitch (200%) was maximal immediately after the CC and dissipated over the next 10 minutes, whereas high-frequency evoked contractions (17%) and isometric voluntary ballistic performance (9-24 %) had their peaks 1 min after CC, and enhancement lasted 5 and 2 min, respectively. The difference in the improvement of the high frequency train (250Hz) compared to the twitch (both evoked electrically), shows that a saturation process limits the magnitude of PAP in successive responses within a train of stimuli. This saturation process had already been demonstrated by Baudry et al. (2005), who observed that PAP saturation increases when stimulation frequency is increased (Baudry et al. 2005). This may be an indication that the impact of PAP on voluntary contractions is limited, since frequencies greater than 100 Hz are comparable to the observed frequencies during voluntary ballistic contractions (Van Cutsem et al. 1998). In a similar study, Baudry and Duchateau (2007b) found that a MVC of 6s was able to increase peak angular velocity during voluntary ballistic contractions (14%), but, in the same way, the magnitude during the voluntary contractions was extremely limited compared to the improvements observed in the peak angular velocity for a single stimulus (twitch: ~182%). In these two studies, the levels of PAP were extremely high and just small increases were observed in voluntary ballistic performance of the thumb adductors at specific intervals in the recovery period. Furthermore, voluntary performance improvements lasted only 2 minutes, even when PAP measured with twitch contractions was significant for 10 minutes. This is an important result and demonstrates the non-linearity between PAP magnitude and acute changes in performance.

Distinct time-course and magnitude differences between PAP (twitch properties) and voluntary performance have been consistently reported in the literature. Consistent with the studies cited above for the thumb adductor, Miyamoto et al. (2011) observed that following an MVC of 6s the concentric voluntary isokinetic torque of the plantar flexors was increased only at 1-3 min after the CC. In contrast, PAP measured by twitch was maximum (178.6%) immediately after the CC, falling exponentially until disappearing at 10 min. It is noted that even at intervals where PAP was still significant (4-5min in the recovery period), voluntary performance was not modified, suggesting that high levels of PAP are necessary to impact voluntary performance, or PAP does not play a decisive role in the acute modulation of performance. It is also possible that fatigue is expressed differently between twitch contractions and high frequency or voluntary contractions. Another interesting aspect was seen by Fukutani et al. (2012), in which 6s MVCs of the plantar flexors were performed with different intensities (40%, 60%, 80% and 100%). The authors observed that all intensities were followed by significant PAP, which was proportional to the intensity of CC. Concentric voluntary torque (180 degrees/s) was only improved after the 80% and 100% MVC conditions. This observation also suggests that contractions of higher intensities and elevated levels of PAP are necessary to contribute to positive changes in performance.

The angular velocity of the main activity tested may also play some role in the manifestation of positive effects associated with PAP. Fukutani et al. (2013) observed that concentric voluntary torque increased 7% immediately after CC only at angular velocity of 180 degrees/s, but not at 30 degrees/s. Similar to the other studies cited above, PAP lasted longer (5 min), while concentric torque increased only immediately after. Interestingly, at both angular velocities the magnitude of the PAP was similar, however, an increase in voluntary torque was observed only in the high speed condition. It has been suggested that the positive effect of a CC and corresponding phosphorylation of myosin RCL has more effect when the magnitude of interaction between actin and myosin filaments has been reduced (Sweeney et al. 1993). For example, potentiation due to prior contraction is greater at a short length where the filaments are further apart than at a long length where Ca^{2+} sensitivity is already enhanced by closer filaments (Rassier and MacIntosh 2002b). It is known that the number of attached cross-bridges decreases as the velocity of fiber shortening is increased (Piazzesi et al. 2007), thus, it can be speculated that at high angular velocities, the effects of PAP (increased sensitivity to calcium due to phosphorylation of myosin RCL) would be able to diminish these effects on voluntary performance. This idea is also supported by the fact that higher PAP (twitch properties) was found during rapid shortening than slow shortening (Babault et al. 2008) and that PAP depends on direction and velocity of ongoing muscle length changes (Gago et al. 2014) .

2.4.2 **Potential factors disrupting the link between PAP and voluntary performance**

In contrast to the studies cited above, other investigations have failed to observe improvements in voluntary performance even with confirmation of PAP (Gossen and Sale 2000; Folland et al. 2008; Hodgson et al. 2008). Gossen and Sale (2000), for example, did not find improvements in peak velocity or power in ballistic dynamic knee extensions (intermediate loads between 15-60% MVC) 15s after a 10s MVC at a time when PAP was significant (53 ±

4%). Hodgson et al. (2008) also did not observe a significant increase in the peak voluntary torque or in the mean RFD (only at some specific time intervals) of plantar flexors after 3x5 s MVC, even when significant PAP was observed (20.7%). Similarly, Folland et al. (2008) reported no significant increase in RFD or isokinetic torque of knee extensors after 10s MVC, at a time when both neural measurements (enhanced H-reflex) and PAP (16%) were clearly evident. It is speculated that when the calcium concentration is high enough to cause activation of all possible cross-bridges, the effects of the phosphorylation of the RLC are minimal (Smith et al. 2014), as seen in a voluntary activity, in which the concentration of calcium is much higher than in a twitch (Fukutani et al. 2012). Maximum voluntary efforts are relatively high-frequency, limiting the possibility that PAP can improve maximum effort performance (MacIntosh et al. 2012). This may explain the large torque increase in the twitch and the absence of improvements in voluntary performance in these studies. Also, it is possible that the assessment of distinct muscle groups (knee extensors, plantar flexors and thumb adductors) with different fiber-type distributions (Johnson et al. 1973) has resulted in different responses since phosphorylation appears to be more prevalent in type II fibers (Hamada et al. 2000, 2003; Vandenboom 2017). In addition, an extremely high PAP level, approximately 150-200% (Baudry and Duchateau 2007a, 2007b) was observed in the studies that reported positive responses, for subsequent voluntary performance. This is in contrast to the studies where the voluntary performance did not change, at times where PAP values were 16-53% (Gossen and Sale 2000; Folland et al. 2008; Hodgson et al. 2008).

When the evaluated voluntary performance involves a more complex task like vertical jumps, the results are even more contradictory. Nibali et al. (2013) conducted an interesting study and observed that 6 of the 8 subjects evaluated, demonstrated PAP at different intervals, but this did not result in increased power or RFD in squat jump. Similarly, 3 of the 8 subjects increased the power, while 5 of the 8 increased the RFD at several intervals, even without PAP in some of the evaluated intervals. Changes in jump-associated variables that did not follow the PAP magnitude suggest that other factors are more involved in voluntary performance enhancement than PAP is. Thomas et al. (2017) observed a significant increase in jump performance 8 minutes after the CC which involved a squat protocol (3x3 reps with 80, 90 and 100% RM). Not only was PAP no longer present at this time, but the twitch was depressed. In this study, an acute neural modulation was also tested, but no changes were observed in measures of voluntary activation or corticospinal excitability. These data suggest that improvement in voluntary performance is mediated by other mechanisms and the neuromuscular basis of this improvement still needs to be elucidated.

Similarly, Prieske et al. (2018) verified that jump performance (CMJ, DJ) was significantly improved even without the coexistence of PAP at the intervals tested. Surprisingly, in the condition in which PAP was present, the jump performances did not change, whereas when the performance improved, PAP was not observed. Thus, the authors also concluded that PAP does not directly translate into voluntary performance enhancements. Pearson and Hussain (2014) did not observe significant PAP 4 min after 3 s, 5 s and 7 s MVCs, nor did jump height increase. Surprisingly, jump performance was decreased even with small twitch torque increase (PAP not significant) observed. Mitchell and Sale (2011) found that 5RM in the back squat generated PAP of 10.7% at 4 minutes of recovery. A 2.9% increase was observed in CMJ height in another session at the same recovery interval using the same squat protocol as CC. The correlation between PAP magnitude and increase in CMJ was not significant ($r = 0.24$). Bergmann et al. (2013) observed that 30 seconds after performing 10 maximal two-legged hops, there was an increase of 32 ± 8% in twitch peak torque of the triceps surae muscles. Drop jump performance was improved by 12% at the same recovery interval. The correlation between PAP and change in drop jump rebound height was not significant ($r^2 = 0.26$).

Based on these studies, we can conclude that for PAP to contribute to an increase in voluntary performance, PAP must be extremely high. However, voluntary performance improvement has also been reported when PAP was not present, and unchanged/diminished performance has been identified when PAP was present. These observations demonstrate that other mechanisms may be more decisive in the acute increases in voluntary performance after a high intensity warm-up and these alternative mechanisms contribute to improved performance that should be referred to as PAPE. These alternative mechanisms still need to be better clarified.

2.4.3 **Phosphorylation of myosin regulatory light chains as the main mechanism related to PAP**

The main physiological mechanism explaining the increase in twitch torque after a previous contraction is the phosphorylation of the myosin regulatory light chains (RLC) due to the transfer of a phosphate group from a high energy ATP to a specific site on myosin (Szczesna 2003; Vandenboom 2017). This is a way to provide a kind of short-term memory for the system, allowing myosin to remember that it was recently activated (MacIntosh 2010). Phosphorylation is mediated by the enzyme myosin light chain kinase (Sweeney et al. 1993; Vandenboom 2017) and increases the sensitivity of the contractile apparatus to the calcium released from the sarcoplasmic reticulum (Sweeney et al. 1993). The modulatory influence of this phosphorylation is exerted via structural changes in the contractile apparatus that influence the formation and kinetics of cross-bridges (Vandenboom 2017). More specifically, phosphorylation increases the mobility of the myosin head by placing it closer to the binding sites on actin. This increases the rate of engagement of cross-bridges (MacIntosh 2010), inducing an increase in the transition from a state of "non-generation of force" to a state of "force generation" (Baudry et al. 2008) and explains the enhanced torque and RFD of an elicited twitch following a CC (MacIntosh 2010).

The relative increase in force for a given increase in calcium sensitivity is greater when the concentrations Ca^{2+} are low, as seen in a twitch (Sale 2002; Hodgson et al. 2005). At high calcium concentrations this increased sensitivity has little effect, as observed in maximal tetanic contractions (Vandenboom et al. 1993; MacIntosh and Willis 2000; Abbate et al. 2000; Sale 2002). The concentration of calcium in a tetanic contraction is proportional to the frequency of activation used (Chin et al. 1997; Glass et al. 2018), so the enhancement of force decreases as frequency of activation increases (MacIntosh and Willis, 2000).

A conditioning contraction can have both positive and negative impacts on contractile response. In addition to potentiation, the conditioning contraction can also result in fatigue, resulting in coexistence of fatigue and potentiation (Rassier and MacIntosh, 2000). When PAP and fatigue are present, it is possible that fatigue will dominate as the activation frequency increases (MacIntosh 2010), simply because the impact of light chain phosphorylation is less.

Increased sensitivity to calcium is also observed at long muscle lengths, independent of RLC phosphorylation, since stretching a fiber also causes the actin filaments to be closer to the myosin heads (MacIntosh 2010). This independent mechanism of altered calcium sensitivity, is interactive, reducing the impact of regulatory light chain phosphorylation at long lengths, since calcium sensitivity is already high (MacIntosh 2010). This is supported by studies that found higher PAP levels at short muscle lengths (Vandervoort and McComas 1983; O'Leary et al. 1997; Rassier and MacIntosh 2002; Place et al. 2005; Kuzyk et al. 2018). Skinned fiber experiments have confirmed that when the lattice spacing is expanded, the sensitivity to calcium is lower (Yang et al. 1998), and the effects of increased calcium sensitivity due to phosphorylation of the regulatory light chains is greater.

Recruiting all fibers during the CC is important to achieve maximum potentiation of the RLC since only RLC of the fibers recruited during contraction can be phosphorylated (Fukutani et al. 2014a). It also appears that type II fibers demonstrate higher phosphorylation and PAP magnitudes after a CC (Gordon et al. 1990; Hamada et al. 2000), which is indirectly corroborated by higher PAP seen in dorsiflexors than in plantar flexors after 10-second MVC (Vandervoort et al. 1983), higher PAP in gastrocnemius compared to soleus muscles (Vandervoort and McComas 1983) and by higher PAP in power athletes compared to endurance athletes (Pääsuke et al. 2007). Furthermore, the activity of the enzyme myosin light chain kinase that regulates phosphorylation, seems to be proportional to the composition of fast fibers of the vastus lateralis (Houston et al. 1985); this would result in greater phosphorylation of myosin RLC in fast-twitch fibers in response to a CC (Sweeney et al. 1993).

In summary, each myosin RLC has a specific site for incorporation of a phosphate molecule (Tillin and Bishop 2009) and this site is phosphorylated when a muscle contraction is initiated. The more intense the contraction, the more fibers are recruited and the greater the level of phosphorylation observed. Obviously, the CC should recruit the same muscle groups as the main performance test, such that the fibers used in the task could be phosphorylated and demonstrate PAP. During the time that the RLCs are phosphorylated, the torque of a twitch is increased (Manning and Stull 1979) due to increased calcium sensitivity and concomitant improvements of interaction between the actin and myosin filaments. The fact that calcium sensitivity is already increased at long lengths makes the phosphorylation less effective and PAP is suppressed in this condition. The effect of this phosphorylation on a subsequent high intensity task is still unclear.

2.5 CONCLUSIONS

Based on the studies analyzed in this review, it can be observed that PAP is a highly reproducible phenomenon and the most accepted mechanism associated with the improvement of the contractile properties is the phosphorylation of the myosin RLC. However, the occurrence of PAP, confirmed by supramaximal electrical stimulation, does not necessarily mean that a voluntary performance will be improved. Studies included in this review that monitored the contractile properties also demonstrated that improvements in voluntary performance were only observed when the PAP level after the CC reached extremely high values (~150%). Conversely, some studies have also observed improvements in voluntary performance at times when PAP was not present. This demonstrates that other mechanisms are more relevant than PAP in the manifestation of acute increases in performance (PAPE). However, this does not eliminate the importance of PAP, but leads us to think that the manipulation of the myosin RLC phosphorylation and the observed increase in the torque of a twitch, after a CC, only translates into optimization of voluntary performance in some specific cases, like when PAP magnitude is extremely high. Therefore, care should be taken when interpreting results when PAP is not measured. It is inappropriate to assume that a muscle that demonstrates PAP will have superior voluntary performance, because that is not always observed.

Conflict of Interest: None of the authors of this paper has a competing interest.

References: The references of the paper are at “references section”.

CHAPTER THREE

3 STUDY TWO: PLYOMETRIC EXERCISE ENHANCES TWITCH PEAK TORQUE OF QUADRICEPS MUSCLES AND INDUCES SPRINT PERFORMANCE ENHANCEMENT IN ELITE TRACK AND FIELD ATHLETES

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Original article

Title

Plyometric exercise enhances twitch peak torque of quadriceps muscles and induces sprint performance enhancement in elite track and field athletes

Key words: Voluntary performance, post-activation performance enhancement, myosin light chains, performance, conditioning contraction, twitch.

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Abstract

Purpose The objective of this study was to analyze the effects of a plyometric conditioning activity (CA) comprised of multiple sets of vertical jumps (3 sets of 5 vertical jumps) on postactvation potentiation (PAP) and on postactvation performance enhancement (PAPE) of 30 m sprints.

Methods Twelve sprint athletes, 10 men (23.5 ± 7.7 years) and 2 women (23.0 ± 2.8 years), performed the procedures to determine the effects of the plyometric CA on 30 m sprints over several time intervals (2, 4, 6, 8, and 10 min). Twitch peak torque (Pt) was also evaluated to determine the magnitude and time-course of the induced PAP at the same recovery intervals.

Results Mixed-model ANOVA with Bonferroni post-hoc verified that there was a difference (faster times) between pretest and 2 min ($p = 0.01$) as well as 4 min ($p = 0.02$) for 30 m sprint times (PAPE) when CA preceded the sprints. Post-hoc analysis revealed significant differences between pretest and 2 min ($p < 0.01$) as well as 4 min ($p = 0.02$) for Pt confirming PAP for 4 min after the plyometric CA. The observed PAP magnitude was 17.04 ± 12.26% and 7.26 ± 8.89% at 2 min and 4 min, respectively.

Conclusions The inclusion of plyometric CA in the warm-up routine improved 30 m sprint performance at 2 min and 4 min time intervals after the CA (PAPE). Since PAP was confirmed with electrical stimulation at the time when sprint performance increased, it was concluded that PAP may have contributed to the observed performance increases.

Keywords: Voluntary performance, postacitvation performance enhancement, myosin light chains, performance, conditioning contraction, twitch.

3.1 INTRODUCTION

It is known that the contraction history contributes to subsequent contractile responses of skeletal muscle (Sale 2002, 2004; Hodgson et al. 2005), affecting its ability to produce force. One consequence of prior muscle contraction is an increased contractile response for a known activation, traditionally evaluated with electrical stimulation (MacIntosh and Willis 2000; MacIntosh et al. 2012). This increase of intrinsic muscle properties is referred to as postactvation potentiation (PAP) and the prior muscle activity is called conditioning activity (CA) (Tillin and Bishop 2009; MacIntosh et al. 2012). Thus, using CA to induce PAP can theoretically lead to increases in contractile response and this may lead to a subsequent improvement in voluntary performance, known as postactvation performance enhancement (PAPE) (Cuenca-Fernandez et al. 2017; Zimmermann, Macintosh and Dal Pupo, 2019).

Physical performance may be affected after a CA either positively or negatively (Chatzopoulos et al. 2007), depending on the balance between fatigue and potentiation (Chiu et al., 2003). From this perspective, several studies have been conducted over the years testing different CA protocols and their effects on athletic performance (Tillin and Bishop, 2009) and see review by Zimmermann, MacIntosh and Dal Pupo (2019). Most studies have used maximal voluntary contractions (Babault et al. 2008; Batista et al., 2011; Baudry and Duchateau, 2007; Baudry et al. 2008) or high intensity dynamic strength exercises as CA (Batista et al., 2007; Bevan et al., 2010; Chatzopoulos et al., 2007; Chiu et al., 2003; Boullosa et al., 2013; Crewther et al., 2011). However, this type of CA is not easy to perform without specific equipment, limiting their use as warm-up before competitions. For this reason, plyometric CA protocols emerge as an attractive alternative; plyometrics can be easily performed by athletes just prior to their competition (Turner et al. 2015). In addition, plyometric exercises can be designed to be more specific in terms of the muscle use during the competition (i.e., stretch-shortening cycle) (Fletcher 2013) allowing muscles used later in the competitive activity to be potentiated (Fukatani et al., 2014).

Previous research using plyometric exercise as CA have found positive results on the performance of drop jumps (Bergmann et al. 2013), vertical jumps (Bridgeman et al. 2016; Chen et al. 2013), and long jump (Bogdanis et al 2017). However, few studies have tested the effect of plyometric CAs on sprint performance. Till and Cooke (2009) found that a single set of 5 vertical jumps did not improve a subsequent 10 and 20 m sprint performance in soccer players. Recent metanalyses showed that multiple sets appear to be more efficient in increasing athletic performance (Seitz and Haff, 2016; Wilson et al., 2013), suggesting that 1 set of 5 vertical jumps is not sufficient (low volume) to trigger positive effects on sprint performance. Conflicting responses after plyometric CA on athletic performance have been attributed to the different CA used, as well as the difference in intensity, volume, and recovery period used (Tillin and Bishop 2009).

An important point in the study of CAs is the training level of the subject evaluated. It has been shown that muscles with a higher percentage of type II fibers may demonstrate higher PAP (Hamada et al., 2000). Thus, considering that elite track and field athletes have higher percentage of type II fibers, it can be speculated that athletes with these capabilities can benefit more from the use of CA. However, to our knowledge, there are no data in the literature confirming whether plyometric CAs are effective to induce PAP. Nor is there evidence that PAPE would result when tested in elite track and field athletes.

Thus, in order to complement the available literature, it is necessary to evaluate the effect of multiple sets of a plyometric CA on sprint performance optimization at different rest intervals after the CA in elite track and field athletes. In addition, to verify PAP time course and its possible contribution to performance optimization, it is necessary to evaluate contractile properties after the CA at the same time intervals where the main performance is tested. It is noteworthy that no study has confirmed PAP after vertical jumps as plyometric CA and it is not known whether the magnitude of PAP after this type of CA may be related to subsequent performance increases (PAPE).

Thus, the objective of this study is to analyze the effects of plyometric CA composed of multiple sets of vertical jumps on the performance of 30 m sprints over different recovery intervals. In addition, contractile properties will be evaluated to determine the presence or not of PAP at the same intervals. The main hypothesis is that plyometric CA will induce PAP on the quadriceps muscles and positively affect the performance of subsequent sprints (PAPE).

3.2 METHODS

Participants

Twelve sprint athletes, ten men (age: 23.5 ± 7.7 years; height: 177.0 ± 8.6 cm; body mass: 70.4 ± 10.1 kg) and two women (age: 23 ± 2.82 years; height: 169.0 ± 0.7 cm; body mass: 55.5 ± 0.7 kg) participated in this study. The athletes were exclusively sprinters with 100 m personal best time ranging from 10.38 to 11.45 s for men and from 11.77 to 11.92 s for women. The following inclusion criteria were adopted: to be included, subjects were engaged in regular training, for at least 3 years, and had competitive experience at the national level. Potential subjects did not have any type of injury that would limit the physical performance during the tests. The selected participants were instructed to avoid training during the evaluations, to eat and hydrate similarly at the same time before the tests, and to avoid caffeine-containing drinks for the 24 hours prior to testing. All study participants were informed about the research objectives and the proposed methodology, and then signed the Informed Consent Form. The study was approved by local ethic committee (CAAE: 11433319.9.0000.0121).

Experimental design

The present study was conducted with two objectives: 1) to verify the influence of a plyometric CA consisting of 3 sets of 5 vertical jumps (independent variable) on the sprint performance (dependent variable); 2) to evaluate the impact of this plyometric CA on PAP of the quadriceps muscles through the application of electrical stimulation. This study used a cross-over design, with a control condition and an experimental condition, in which the same participants performed both conditions.

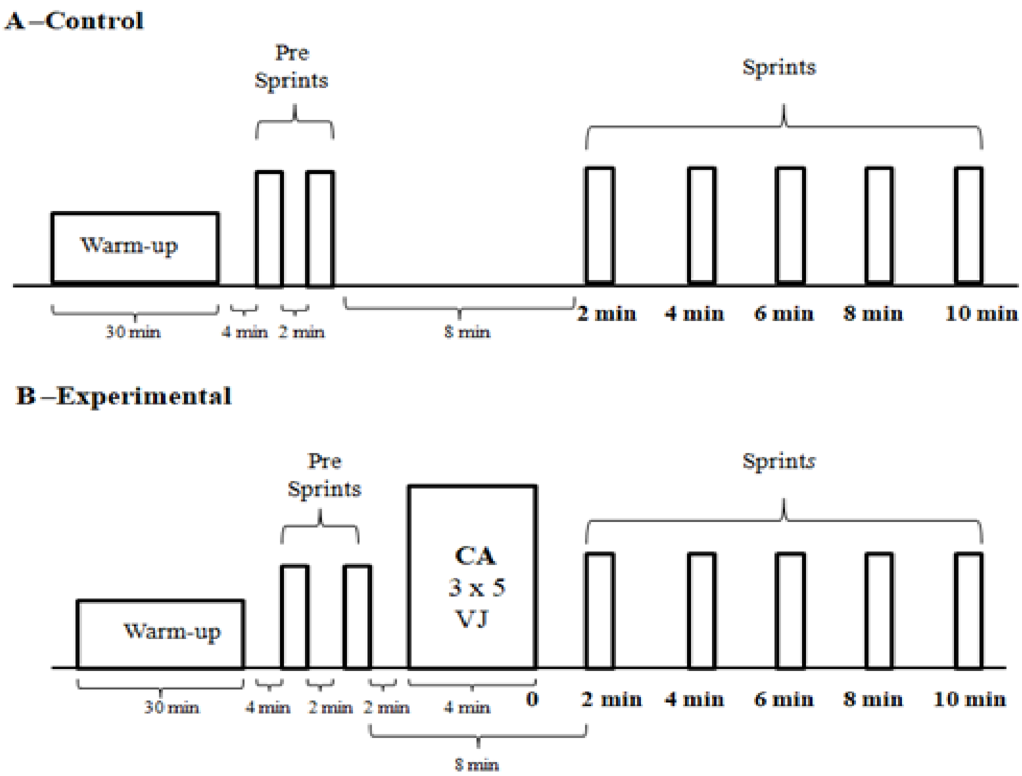
The tests were conducted over four days. On the first day, athletes were familiarized with the plyometric CA, sprints, and application of the electrical stimulus (twitch). On the second and third day (at least 24 hours apart) the athletes returned to determine the sprint performance for control (without previous plyometric CA) or experimental conditions (with previous plyometric CA), in a randomized order. On the fourth day, at least 24 hours after, the time-course of twitch contractile response was evaluated with and without CA.

Determination of the effect of the CA on sprint performance

Athletes performed their warm-up and sprint trials on an official synthetic track, in the control condition without CA and in the experimental condition with CA, separated by at least 24 hours. Prior to the tests, a general warm-up was performed simulating what is usually performed by the athletes before competitions This general warm-up consisted of 5 min of low intensity running (jogging), followed by specific coordination exercises for up to 10 min; three accelerations of 50 m and 2 maximum effort short sprints (10 m) followed by 2 maximum 30 m sprints (2 min interval). These 2 maximum 30 m sprints served as the pretest measure of performance. In the experimental condition, the plyometric CA (3 x 5 maximal vertical jumps) was included 2 min after the second pretest sprint. Following the CA, subjects performed maximum sprints at 2, 4, 6, 8, and 10 min. These time intervals were selected based on the metanalyses by Wilson et al (2013) and Seitz et al (2015) which showed that intervals of up to 10 min are adequate to increase power production after a CA. The same procedures were performed in the control condition, but without inclusion of CA. Figure 2 illustrates the protocol for the sprints.

The sprints were timed electronically using photocells (Speed Test 6.0, CEFISE, SP, Brazil) at the start, 10 and 30 m, positioned at the height of the subject's hip. The participants initiated their sprint at 0.5 m before the first photocell. The timing started automatically when the athlete interrupted the first light beam and ended when the last light beam was interrupted.

Figure 2. Experimental design for sprint performance measurement.

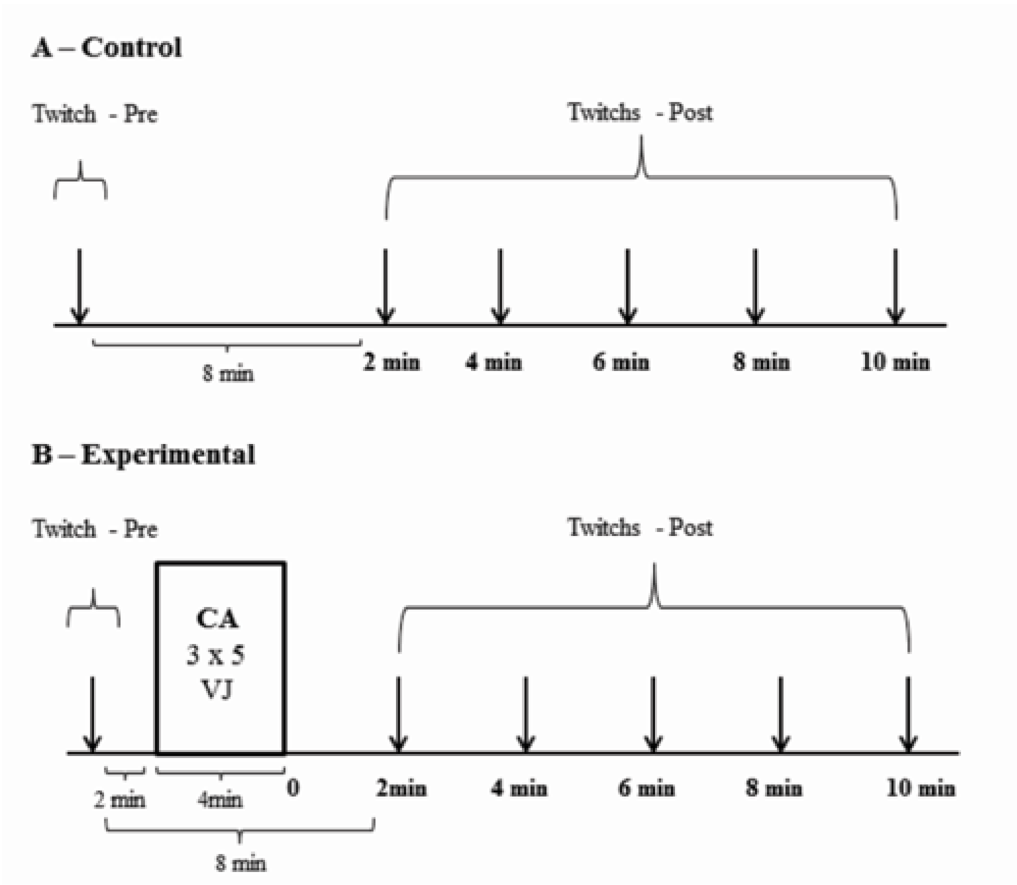


Determination of twitch contractile properties

Participants were positioned on the isokinetic dynamometer (Biodex Medical Systems 4, Shirley, NY, USA) with the lateral epicondyle of the knee aligned with its axis. The knee was positioned at 70 degrees of flexion (0 = full extension). Inextensible bands fixed the participant's trunk, waist, and thigh. The right leg was fixed to the dynamometer arm just above the ankle joint. Two self-adhesive electrodes (ValuTrode, Axelgaard, Fallbrook, Ca, USA) for surface stimulation: the anode (97.5 cm^2 area) was positioned below the gluteal fold and the cathode (circular, 5 cm^2) in the femoral triangle over the femoral nerve. The participant remained seated quietly for 10 min to allow dissipation of any PAP resulting from prior activation. Initial twitch contractions served as control condition. Rectangular pulses of 0.2 ms duration were applied (Digitimer, Hertfordshire, UK) initially with submaximal current, and high voltage (400 V). Electrode placement was adjusted to yield the highest twitch torque. After detecting the best electrode position, the current of the electrical stimulation was progressively increased until the highest twitch torque was observed. For this, the stimulus intensity was increased by approximately 15 mA at each 5 s interval until three successive increases of current no longer resulted in torque increases (Johnson et al., 2019). An intensity 50% above that was then selected for subsequent supramaximal stimulation (Bergmann et al. 2013), thus ensuring the activation of all motor units.

Two conditions were performed to determine the effects of the CA on the contractile properties: twitches at control (without previous plyometric CA) and experimental condition (with previous plyometric CA). In the experimental condition, participants performed the CA and immediately after were carefully positioned in the dynamometer chair with the electrodes remaining in the same position. Supramaximal stimulations (150% of maximum current) were applied at the same time intervals (2, 4, 6, 8, and 10 min) to determine the peak torque (Pt) at each of these intervals. During the control measures, the participants remained seated on the dynamometer and were instructed to relax and not voluntarily contract the muscles evaluated during the entire session. The presence or absence of PAP was calculated as the percentage difference in magnitude of the peak twitch torque of pre-CA twitch compared to twitches applied after the CA, as follows: PAP = (Post Twitch / Pre-CA Twitch x 100), described by Jordan et al. (2009). Figure 2 illustrates the protocol design for the twitches in the isokinetic dynamometer.

Figure 3. Control (A) and experimental condition (B) for determination of torque twitch.



Statistical analysis

The reliability of the pre-condition sprint times was calculated using the Intraclass Correlation Coefficient (ICC), with the following classification: <0.50 poor; 0.50-0.75 moderate; 0.75-0.90 good; and> 0.90 excellent (Fleiss, 1986). The Typical Error of Measurement (TEM) was also calculated: (standard deviation of the differences / square root of two). In addition, the Smallest Worthwhile Change (SWC) was calculated for 0.2 (small change) and 0.6 (moderate change). The sensitivity of the variables was verified by comparing the TEM with the SWC. Mixed-model ANOVA (time x condition) with Bonferroni post-hoc was used for analysis. Data sphericity was tested by Mauchly tests and the Greenhouse-Geisser correction was used when necessary. Effect sizes were calculated and classified as small (<0.40), moderate (0.41 - 0.79) and large (> 0.80) (Cohen 1988). The significance level adopted was $p < 0.05$. Statistical procedures were performed using SPSS® (Statistical Package for Social Sciences) v.17.0 (SPSS Inc., USA) software.

3.3 RESULTS

Table 2 shows the reliability and sensitivity results of the sprint-related and twitch variables. Good reliability was observed for sprint performance, especially for the 30 m sprint times. Twitch peak torque demonstrated excellent reliability (ICC values >0.90). In addition, the sensitivity analysis showed that all variables presented TEM (absolute) smaller than 0.2 SWC (small effect size), which means that even the small changes observed in these variables are real and not due to measurement error.

Table 2. Reliability and sensitivity of pre-measurements between control and experimental conditions for sprints and twitch peak torque.

	Control_Pre Mean±SD	**Experimental_Pre Mean±SD**	**ICC**	**TEM**	**TEM (%CV)**	**$SWC_{0.2}$**	**$SWC_{0.6}$**
Sprint time 0-10 m (s)	1.676±0.127	1.731±0.151	0.72	0.018	1.11%	0.027	0.083
Sprint time 0-30 m (s)	3.990±0.239	4.046±0.266	0.89	0.037	0.93%	0.050	0.151
Twitch Pt (N·m)	43.52±14.26	41.72±13.67	0.99	0.39	0.91%	2.79	8.38

Caption: SD = Standard deviation; ICC = Intraclass correlation coefficient; TEM= Typical error of measurement; SWC = Smallest worthwhile change (0.2=small changes; 0.6=moderate changes). Pt= Peak torque

For 10 m sprint performance, ANOVA showed condition x time interaction ($F = 3.04$; $p = 0.01$) (Figure 3A), in which it was observed a difference between the time interval 4 min and 10 min ($p = 0.02$) in the experimental condition, indicating that the times were increasing over time in this condition. In the control condition no significant differences were found for any interval ($p > 0.05$). ANOVA also showed condition x time interaction ($p < 0.01$; $F = 3.61$) for the 30 m sprint performance (Figure 3B). Post-hoc analysis revealed that there was a significant decrease in 30 m sprint time at 2 min ($p = 0.01$) and 4 min ($p = 0.02$), compared with pretest value, for experimental condition. The values decreased from 4.046 ± 0.266 s in the pre to 3.936 ± 0.237s (-2.78%) and to 3.966 ± 0.247s (-2.0%) at 2 min and 4 min, respectively. In the control condition, no significant differences were found across all times ($p > 0.05$).

Figure 4. Comparison of sprint times between conditions and time intervals. Panel A: 10 m sprint; Panel B: 30 m sprint. * Indicates difference from pre values; #Indicates difference from 4 min interval values.

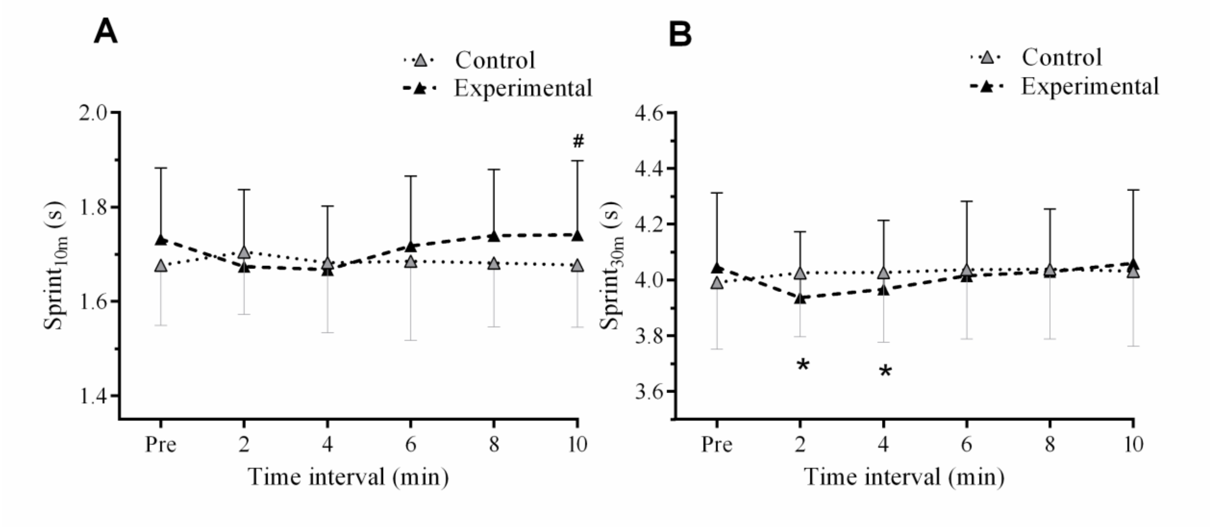


Table 3 shows the percent change and the effect sizes comparing pre with each time interval. We can observe moderate effect sizes at the 4 min interval for 10 m sprints and at the 2 min interval for 30 m sprints, for the experimental condition.

Table 3. Percent changes and effect sizes of sprint performance when compared to pre condition.

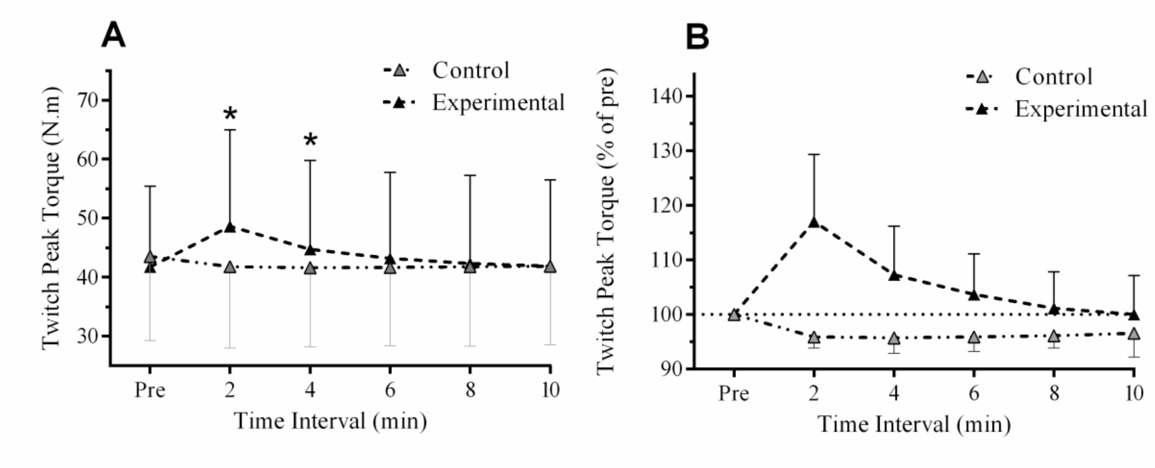
	Pre vs. 2 min Δ% (ES)	Pre vs. 4 min Δ% (ES)	Pre vs. 6 min Δ% (ES)	Pre vs. 8 min Δ% (ES)	Pre vs. 10 min Δ% (ES)
Sprints**_**10m					
Control	+1.68% (0.22)	+0.34% (0.04)	+0.53% (0.06)	+0.30% (0.03)	+0.03% (0.00)
Experimental	-3.45% (0.36)	-3.68% (**0.45**)	-0.83% (0.09)	+0.43% (0.05)	0.53% (0.05)
Sprints**_**30m					
Control	+0.87% (0.15)	+0.89% (0.14)	+1.14% (0.18)	+1.19% (0.19)	+1.01% (0.16)

Experimental	-2.78% (**0.43**)	-2.00% (0.30)	-0.77% (0.11)	-0.40% (0.06)	+0.33% (0.05)

ES: *effect size;* Δ%: percent changes from pre-test

Regarding the effects of the plyometric CA on PAP (i.e., effects on peak torque) there was significant condition by time interaction (p <0.01; F = 25.64) indicating that the effects over time were different between conditions (Figure 4 - A). In the control condition there was no difference at any time (p> 0.05) compared to pre. On the other hand, in the experimental condition post-hoc analysis verified significant increase from pre to 2 min (p <0.01) and 4 min (p = 0.02), demonstrating that twitch Pt remained elevated for 4 min after the plyometric CA. The twitch peak torque variation in relation to pre values of each condition (PAP magnitude) is expressed as percent of pretest values (Figure 4 - B).

Figure 5. Variation of twitch peak torque for control and experimental condition at each time interval. * Indicates difference from pretest values. A: Absolute values (Nm). B: Values expressed as % of pretest at each subsequent time.



3.4 DISCUSSION

The aim of this study was to evaluate the effects of a plyometric CA on 30 m sprint performance and on the appearance of PAP, at different recovery intervals: 2, 4, 6, 8 and 10 min. The hypothesis was that the plyometric CA would induce PAP in the quadriceps muscles and positively affect 30-m sprint performance. The main finding was that the plyometric CA significantly increased the 30-m sprint performance (PAPE) at 2min and 4min intervals, but not at the other times assessed. Additionally, at 2 min and 4 min, there was an increase in twitch torque (PAP) of quadriceps muscles evaluated with electrical stimulation indicating greater twitch force for a given stimulation. Thus, the hypothesis of the study was confirmed, indicating that sprint performance enhancement may be related to PAP in the quadriceps muscles.

The most accepted physiological mechanism associated with PAP is the phosphorylation of the myosin regulatory light chain (RLC) due to the transfer of a phosphate group from a high energy ATP to a specific site in the myosin light chains (Vandenboom, 2017). This allows myosin to remember that it was recently activated providing a kind of short-term memory for the system (Macintosh, 2010). Phosphorylation increases the sensitivity of the contractile apparatus to calcium released from the sarcoplasmic reticulum, generating structural changes in the contractile apparatus that have a positive influence on cross-bridge kinetics (Vandenboom, 2017). This change increases the rate of force development and enhances submaximal force of the muscles (MacIntosh, 2010).Type II fibers demonstrate higher levels of phosphorylation and consequently higher PAP magnitude after a CA (Hamada et al 2003), because the activity of the enzyme, myosin light chain kinase that regulates phosphorylation, is greater in type II fibers of the vastus lateralis (Houston et al. 1985) than in type I fibers. This partially explains the higher PAP verified for athletes involved in sports which require elevated power, compared to endurance athletes (Passuke et al 2007). Taking this into account, in our study, we evaluated elite sprinters, who would benefit more from a CA, since it is expected that this population has a higher type II fiber composition in their vastus lateralis muscles. The confirmation of PAP (augmented twitch Pt) in the quadriceps muscles with electrical stimulation and the positive performance results obtained at 2min and 4 min (faster 30m times) are consistent with this assumption.

Until the present study, PAP and consequent PAPE in sprints in elite track and field athletes using vertical jumps as CA had not been confirmed. In fact, only two recent studies measured twitch Pt to confirm PAP after a plyometric CA (Bergman et al. 2013, Johnson et al. 2019). However, Johnson et al. (2019) did not check PAP influence on subsequent voluntary performance and Bergmann et al. (2013) tested the influence of 10 maximal hops only on drop jump rebound height, leaving doubt if PAP could actually contribute to improvements in a more complex sport activity, like sprinting. In the present study, PAP of the quadriceps muscles was confirmed at 2 min and 4 min after the plyometric CA (17.04 ± 12.26% and 7.26 ± 8.89%, respectively), the same time intervals at which sprint performance enhancements were found (-2.78% and -2.0% at 2 min and 4 min, respectively). This suggests that the PAP phenomenon may have influence on the performance enhancement (PAPE) observed.

The results from the present study appear to be consistent with several other studies in which enhanced sprint performance has been reported after a plyometric CA (Lima et al., 2011; Byrne; Kenny and O'Rourke, 2014; Turner et al., 2015; Creekmur et al., 2016; Kummel et al., 2016). However, these studies have not confirmed the presence of PAP at the time of the PAPE. In fact, some of these studies observed PAPE at a time when PAP would not be expected. This suggests that enhanced sprint performance after the CA can occur by other mechanisms such as temperature increases (Bishop 2003; McGowan et al. 2015; Silva et al. 2018), increases in the circulating concentration of testosterone (Crewther et al. 2011), increased excitability of motoneurons (Folland et al. 2008), increased recruitment of motor units (Tillin and Bishop 2009), acute elevations in plasma catecholamine levels (Cairns and Borrani 2015), learning effect and familiarization with the main task (MacIntosh et al. 2012) or placebo effect and subject motivation (Beedie and Foad 2009). Therefore, it is important to keep in mind that PAPE may have occurred in this study due to these mechanisms in conjunction with PAP, not PAP alone.

An important aspect to be highlighted is that each sprint could generate additional PAP (or fatigue) which would affect the subsequent sprint. However, it was observed that the sprint performance did not change over the sprints in the control condition, showing the plyometric CA was responsible for inducing changes on sprint performance in the experimental condition. However, the changes were found only for the 30 m sprint times, while changes for 10 m did not reach significance. In spite of this, the time difference for 10 m was nearly as large as the time difference for 30 m; the higher speed at 10 m in the experimental condition may have contributed to making the overall difference significant for 30 m.

Positive PAP effects have been observed only when there is an optimal recovery interval between the CA and evaluation of the twitch response. This interval must allow recovery from the fatigue generated by the CA while the increased contractile response, reflected by enhanced peak torque, is not dissipated (Tillin and Bishop, 2009). Studies that sought to verify the effects of plyometric CA on performance enhancement (PAPE) found positive results at recovery intervals ranging from 0 to 15 minutes after the CA (Lima et al., 2011; Byrne; Kenny and O'Rourke, 2014; Turner et al., 2015 ; Creekmur et al., 2016; Kummel et al., 2016). PAP after a plyometric CA was dissipate within 6 minutes after drop jumps in the quadriceps muscles (Johnson et al., 2019) and 4 min after our CA protocol of 3 sets of 5 maximal vertical jumps. So, it is important to emphasize that PAP could no longer be present when PAPE was found in some of these studies. This shows the importance of evaluating twitch contractile properties to guarantee the presence of PAP. Otherwise, as stated before, other mechanisms are contributing to the PAPE. Furthermore, the recovery interval must be carefully selected, since this interval depends of the type of CA and the training level of the subjects evaluated (Seitz et al 2015). In the present study, the positive results at 2 min and 4 min indicate that these recovery intervals are ideal for balancing fatigue and increasing contractile response of the muscles when 3 sets of 5 vertical jumps were used as CA in elite sprinters.

Plyometric CA volume is also an important factor when considering PAPE. Low plyometric CA volumes have already been shown to have no effect on sprint performance (Till and Cooke, 2009), while volume greater than 10 jumps seems to decrease sprint time (Lima et al., 2011; Byrne; Kenny and O'Rourke, 2014; Turner et al., 2015; Creekmur et al., 2016; Kummel et al., 2016), but these improvements occur predominantly at times when PAP would not be present. In our study, 15 jumps (3 x 5) was enough to generate PAP and also improvements in sprint performance, demonstrating that this volume seems to be ideal to trigger positive responses at 2 min and 4 min recovery intervals. The magnitude of PAP in the quadriceps muscles after our protocol (17.04 ± 12.26% and 7.26 ± 8.89% for 2 min and 4 min respectively) is modest, compared to previously reported twitch enhancement after plyometric CAs in the literature. Johnson et al., (2019) found increases of 23% immediately after drop jumps and Bergmann et al (2013) found 32% enhancement 30 s after 10 maximal hops as CA.

Lately, it has been found that the training level of the subjects tested seems to influence the manifestation of the positive effects of CAs (Chiu et al. 2003; Berning et al. 2010). The main explanation is due to improved ability to activate large motor units that increase with training time, affecting the amount of PAP generated and diminished fatigue associated with CA (Kilduff et al. 2007). Theoretically, in addition to more PAP, athletes with higher training and strength may also demonstrate less fatigue after performing a CA compared to sedentary subjects (Chiu et al. 2003), obtaining greater advantage. As previously discussed, it is suggested that strength level and increases in performance are due to higher proportion of type II fibers in strength- and power-trained athletes, which leads to high PAP magnitude (Hamada 2003). Due to this, highly trained power athletes could be more positively affected by PAP effects than other populations. Indeed, the potential benefits that these small increases in performance related to the use of CAs, are more interesting especially for elite athletes (French et al. 2003), due to the similar level of performance observed in competitions. In our study, a decrease of approximately 2% in 30m sprint time was observed, which may be the differential for a competition medal, especially in highly trained elite athletes.

In summary, it was verified that the use of previous plyometric activities enhance muscle function (PAP) and allows acute sprint performance improvement (PAPE). In our study, we used 3 sets of 5 vertical jumps as CA generating approximately 2-3% improvement in subsequent 30-m sprint performance at 2 min and 4 min recovery intervals. The confirmed increase in twitch Pt of quadriceps muscles in these same time intervals suggest that sprint performance enhancement may be related to PAP phenomenon in the quadriceps muscles. However, we cannot assume a cause and effect relationship and other PAPE mechanisms may also have been involved in the observed sprint performance enhancement in conjunction with PAP.

3.5 PRACTICAL APPLICATIONS

The present study shows that a simple plyometric protocol that can be performed easily before competition was found to induce PAP and improve 30m sprint performance. Since both plyometrics and sprinting include stretch-shortening cycle, it can be speculated that matching the nature of the CA with the main performance task seems to be a good way to use the benefits of a CA in sporting context. Furthermore, since plyometric CA activate multiple muscle groups and do not require specific skill set and techniques, it is very practical for sport coaches and conditioning specialists to use with their athletes before competitions or during training sessions. One should only be aware that the contractile properties remained enhanced only for 4 min after 3 sets of 5 vertical jumps, during which sprint performance was also improved. The protocol used in our study could be beneficial not only for track and field athletes, but also for team sports where sprints are performed, like soccer, football, rugby, etc. In these circumstances, it is the responsibility of the coach to include the plyometric CA to induce PAP in the precise moment before the main task desired, given that PAP dissipates in about 4 minutes after which the possible performance improvement (PAPE) due to this phenomenon is lost.

Conflict of Interest: None of the authors of this paper has a competing interest.

References: The references of the paper are at "references section".

4 CONCLUSIONS

It can be concluded with the first study that only the presence of PAP, which can be confirmed with electrical stimulation, does not guarantee optimized voluntary performance. The systematic review showed that PAP optimized voluntary performance only when it magnitude reaches extreme values. Also, it was found studies where performance was optimized when PAP was not present, demonstrating that PAPE mechanisms also can improve performance, even without PAP at the time that the main activity was tested. This shows that myosin RLC phosphorylation and the observed increase in the torque of a twitch, after a CA, only translates into optimization of voluntary performance in some specific cases, like when PAP magnitude is extremely high. Therefore, this demonstrates that care should be taken when relating the PAP phenomenon to voluntary performance increases without its correct measurement through electrical stimulation. It is inappropriate to assume that a muscle that demonstrates PAP will have superior voluntary performance, because that is not always observed.

The second study showed that the use of previous plyometric activities enhance muscle function (PAP) and allows acute sprint performance improvement (PAPE). The use of 3 sets of 5 vertical jumps as CA improved in approximately 2-3% the subsequent 30-meter sprint performance at 2 min and 4 min recovery intervals. The confirmation of PAP through electrical stimulation at the same recovery intervals was also verified and our result suggest that the enhancement of sprint performance may be partly related to PAP, since we found improvements of performance only at the same recovery intervals where PAP was present. In this study, PAP lasted only 4 minutes, after which the suggested performance improvement (PAPE) due to this phenomenon would be lost. However, it is important to take into account that there is no cause and effect relationship and that any other PAPE mechanisms may have been also involved in the observed performance of the sprints in conjunction with PAP.

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APPENDIX A – TCLE

UNIVERSIDADE FEDERAL DE SANTA CATARINA
CENTRO DE DESPORTOS

TERMO DE CONSENTIMENTO LIVRE E ESCLARECIDO

Você está sendo convidado a participar como voluntário da pesquisa intitulada: "**Exercícios pliométricos como atividade condicionante para induzir PPA e seus efeitos na performance voluntária**", a ser realizada junto ao Laboratório de Biomecânica (BIOMEC) vinculado ao Centro de Desportos (CDS) da Universidade Federal de Santa Catarina (UFSC). O objetivo do estudo será verificar a influência de uma atividade condicionante (AC) pliométrica na manifestação de potencialização pós-ativação (PPA) e na performance de contrações explosivas e de *sprints* de 30 metros. A PPA tem sido relacionada à aumentos da performance atlética, porém, poucos estudos utilizaram atividades pliométricas confirmando a existência de PPA nos momentos em que a performance foi avaliada. Sendo assim, este estudo busca elucidar se AC pliométrica de fato desencadeia PPA e se isso otimiza a performance voluntária.

Com sua adesão ao estudo, você ficará disponível para a pesquisa em quarto dias: 1º dia) realização de uma familiarização com os protocolos de AC pliométrica e com a realização dos *sprints* 2º dia) realização na condição controle do protocolo de *sprints,* sendo realizado 6 *sprints* máximos de 30 metros em intervalos previamente determinados (pré, 2min, 4min, 6min, 8 min e 10min). 3º dia) realização na condição experimental do protocolo de *sprints,* sendo realizado 6 *sprints* máximos de 30 metros em intervalos previamente determinados (pré, 2min, 4min, 6min, 8 min e 10min), da mesma forma que o dia anterior, porém, com a inclusão da AC pliométrica e; 4º dia) você será posicionado no dinamômetro isocinético (Biodex) e dois eletrodos serão utilizados para avaliação da capacidade do seu músculo contrair através de breves impulsos elétricos. Também serão realizadas contrações explosivas voluntárias breves para determinar a sua capacidade de produção de torque. Um agendamento prévio antes de cada avaliação pelos pesquisadores e em caso de não obtenção da aprovação para realização dos testes (1° dia) a coleta de dados não ocorrerá nesse dia. Você não realizará exercícios intensos nos dias dos testes e não poderá consumir cafeínas 12 horas antes do início dos protocolos, além de comparecer alimentado e hidratado. Caso você sinta necessidade, será fornecida água para durante as avaliações.

Para participar deste estudo você deve estar apto a realizar esforço físico de alta intensidade. Devido a tal esforço, poderão ocorrer sintomas como fadiga, sensação de cansaço e náuseas. Adicionalmente, nos dias da realização dos testes, bem como nos dias subsequentes, a presença de dores musculares podem ocorrer. Durante a realização dos pulsos elétricos, pode haver leve desconforto. Caso o desconforto temporário não seja tolerável por você, o teste será suspenso imediatamente, sendo retomado apenas se você concordar e estiver disposto. Será respeitado seu limiar de dor, e não será aplicado nenhum estímulo mais forte do que você não consiga tolerar. Todos os pesquisadores são capacitados e sabem reagir em casa de urgência, caso necessário durante os procedimentos. As informações e dados aqui coletados são confidenciais e só serão utilizados nesse estudo, sua identidade não será revelada. A quebra de sigilo sempre é uma possibilidade, mesmo que de forma involuntária e não intencional, podendo ser um risco a ser considerado.

Quanto aos benefícios e vantagens em participar deste estudo, você estará contribuindo com o desenvolvimento da ciência do esporte e no avanço da pesquisa em biomecânica. Através dos resultados dessa investigação, uma estratégia de aquecimento utilizando-se de atividades condicionantes prévias precisas poderá ser melhor delineada, beneficiando treinadores e atletas na busca do desempenho esportivo máximo e na superação de resultados individuais. Além disso, você terá informações acerca da capacidade de produção de torque de seu músculo, bem como, poderá conhecer os protocolos de atividades condicionantes e utilizá-las em sua rotina de treinamentos.

Nenhuma compensação financeira por sua participação na pesquisa poderá acontecer pois a legislação brasileira não permite, porém, caso você tenha alguma despesa em decorrência da participação, você será ressarcido, tais como transporte e alimentação, que serão integralmente ressarcidas pelos pesquisadores. A sua participação na pesquisa é isenta de despesas e você pode desistir e se retirar do estudo a qualquer momento, sem qualquer justificativa.

Caso aceite participar da pesquisa,toda assistência necessária lhe será prestada e você sempre estará acompanhado pelo grupo de pesquisadores, que estarão a disposição acerca de qualquer dúvida que você tiver. Os resultados obtidos a partir desse trabalho poderão ser utilizados para confecção de artigos e apresentações em congressos, sendo que serão apresentados somente os resultados gerais e seu nome e privacidade será preservada. Você poderá solicitar indenização caso tenha algum prejuízo material ou imaterial em decorrência da pesquisa, de acordo com a legislação vigente e amplamente consubstanciada.

O pesquisador responsável, que também assina este documento, declara que todos os procedimentos serão conduzidos de acordo com o que preconiza a Resolução 466/12 de 12/06/2012. Você pode entrar em contato, em caso de dúvidas acerca dos objetivos e procedimentos da pesquisa, com o pesquisador pelo telefone (48) 3721-8530, no e-mail: j.dalpupo@ufsc.br, ou ainda no endereço Rua Maria Eduarda, n° 526, Pantanal, Florianópolis/SC (88.040-250). Você também poderá entrar em contato com o Comitê de Ética em Pesquisa com Seres Humanos da UFSC pelo telefone (48) 3721-6094, no email: cep.propesq@contato.ufsc.br, ou pelo endereço Rua Desembargador Vitor Lima, nº 222, sala 401, Trindade, Florianópolis/SC (88.040-400). Esse documento traz informações importantes de contato e sobre suas garantias como participante da pesquisa, sendo assim, duas vias deste documento estão sendo rubricadas e assinadas por você e pelo pesquisador responsável. Uma das vias ficará em sua posse, conforme o item IV.3 (f) da Resolução 466/2012.

Agradecemos a sua colaboração e participação.

____

Prof. Dr. Juliano Dal Pupo

Pesquisador responsável

DECLARAÇÃO DE CONSENTIMENTO DO PARTICIPANTE

Eu, ____, R.G. ______________________, declaro que fui informado sobre todos os procedimentos da pesquisa e que recebi de forma clara e objetiva todas as explicações pertinentes ao projeto. Estou ciente e esclarecido dos procedimentos, optando por livre e espontânea vontade participar da pesquisa.

Assinatura: ____

Florianópolis, ____/____/____.

ATTACHMENT A – PARECER CONSUBSTANCIADO DO CEP

UNIVERSIDADE FEDERAL DE
SANTA CATARINA - UFSC

PARECER CONSUBSTANCIADO DO CEP

DADOS DO PROJETO DE PESQUISA

Título da Pesquisa: EXERCÍCIOS PLIOMÉTRICOS COMO ATIVIDADE CONDICIONANTE PARA INDUZIR PPA E SEUS EFEITOS NA PERFORMANCE VOLUNTÁRIA

Pesquisador: Juliano Dal Pupo

Área Temática:

Versão: 1

CAAE: 11433319.9.0000.0121

Instituição Proponente: UNIVERSIDADE FEDERAL DE SANTA CATARINA

Patrocinador Principal: Financiamento Próprio

DADOS DO PARECER

Número do Parecer: 3.293.555

Apresentação do Projeto:

Projeto de mestrado de Haiko Bruno Zimmermann sob orientação do professor Juliano Dal Pupo, do Programa de Pós-Graduação em Educação Física. Estudo de caráter experimental por incluir avaliações antes e após a aplicação de um tratamento (atividade condicionante pliométrica), com 22 participantes. Serão atletas da modalidade de Atletismo, de provas de corrida de velocidade, do sexo masculino e feminino, de nível estadual, nacional e internacional. Os atletas serão convidados a participar do estudo, sendo sua seleção de forma intencional e não probabilística. Serão selecionados participantes que atendam aos requisitos dos critérios de inclusão. O contato inicial com os sujeitos se dará via redes sociais ou e-mail. Critérios de inclusão: a) possuir experiência de no mínimo três anos com treinamento visando alto rendimento em provas de velocidade e ou/barreiras; b) estarem envolvidos em um treinamento de modo regular, sendo ao menos 5 vezes/semana; c) não possuírem nenhum tipo de lesão que limite a aplicação dos testes, d) assinar um termo de consentimento livre e esclarecido (TCLE); b) Critérios de exclusão: a) se lesionarem no período da coleta de dados; b) desistirem da realização dos testes por vontade própria; c) apresentarem algum desconforto que impeça a realização dos sprints com esforço máximo.
Intervenções: Serão utilizados um grupo controle e um grupo experimental para verificar efeito do tratamento na performance voluntária. O estudo será conduzido em três momentos distintos (M1, M2 E M3) para contemplar os seguintes objetivos: M1) analisar os efeitos da AC pliométrica

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(variável independente) no tempo de sprints de 30 metros (variável dependente) ao longo de vários momentos na recuperação (30 s, 2min, 4min, 7min e 10min); M2) analisar se a AC pliométrica induz performance após ativação (PPA), através da variação do pico de torque e a taxa de desenvolvimento de torque em um twitch (pulso simples) (variável dependente) antes e após a realização da AC; M3)analisar se a AC pliométrica (variável independente) induz melhoras na performance de contrações explosivas voluntárias (variável dependente).

Objetivo da Pesquisa:

Objetivo Primário: Analisar os efeitos de uma atividade condicionante (AC) pliométrica na manifestação de performance após ativação (PPA) e na otimização da performance voluntária.

Objetivos Secundários: •Analisar o pico de torque no twitch antes e após a realização de uma AC pliométrica. •Analisar a taxa de desenvolvimento de força no twitch antes e após a realização de uma AC pliométrica.•Analisar o pico de torque em uma contração explosiva voluntária isométrica antes e após a realização de uma AC pliométrica.•Analisar a taxa de desenvolvimento de força em uma contração explosiva voluntária isométrica antes e após a realização de uma AC pliométrica•Analisar o desempenho em sprints de 30 metros antes e após a realização de uma AC pliométrica.•Fazer associações entre mudanças no pico de torque e taxa de desenvolvimento de força no twitch (PPA) com mudanças na performance das contrações explosivas voluntárias isométricas.•Fazer associações entre mudanças entre mudanças no pico de torque e taxa de desenvolvimento de força no twitch (PPA) com mudanças na performance de sprints de 30 metros.

Avaliação dos Riscos e Benefícios:

Análise adequada dos riscos e benefícios.

Riscos: Poderão ocorrer sintomas como fadiga, sensação de cansaço e náuseas. Adicionalmente, nos dias da realização dos testes, bem como nos dias subsequentes, a presença de dores musculares pode ocorrer. Durante a realização dos pulsos elétricos, pode haver leve desconforto. Caso o desconforto temporário não seja tolerável por você, o teste será suspenso imediatamente, sendo retomado apenas se você concordar e estiver disposto. Será respeitado seu limiar de dor, e não será aplicado nenhum estímulo mais forte do que você não consiga tolerar. Todos os pesquisadores são capacitados e sabem reagir em caso de urgência, caso necessário durante os procedimentos. As informações e dados aqui coletados são confidenciais e só serão utilizados nesse estudo, sua identidade não será revelada. A quebra de sigilo sempre é uma possibilidade, mesmo que de forma involuntária e não intencional, podendo ser um risco a ser considerado. Caso aceite participar da pesquisa, toda assistência necessária lhe será prestada e você sempre estará acompanhado pelo grupo de pesquisadores, que estarão a disposição acerca de qualquer dúvida que você tiver.

Benefícios: você estará contribuindo com o desenvolvimento da ciência do esporte e no avanço da pesquisa em biomecânica. Através dos resultados dessa investigação, uma estratégia de aquecimento utilizando-se de atividades condicionantes prévias precisas poderá ser melhor delineada, beneficiando treinadores e atletas na busca do desempenho esportivo máximo e na superação de resultados individuais. Além disso, você terá informações acerca da capacidade de produção de torque de seu músculo, bem como, poderá conhecer os protocolos de atividades condicionantes e utilizá-las em sua rotina de treinamentos.

Comentários e Considerações sobre a Pesquisa:

Sem comentários adicionais.

Considerações sobre os Termos de apresentação obrigatória:

Folha de rosto assinada pelo pesquisador responsável e pela Coordenadora do Programa de Pós-Graduação em Educação Física/CED/UFSC. Autorização institucional, nos termos da resolução 466/12, assinada pelo Diretor do Centro de Desportos/UFSC. Início da coleta de dados deverá ocorrer em junho de 2019 (piloto) e julho de 2019 (com participantes). Orçamento de R$ 245.585,00, não informa fonte ou agencia de fomento financiadora. TCLE atende as exigências da resolução 466/12.

Recomendações:

Excluir do TCLE a frase "Esses dados serão fornecidos gratuitamente aos participantes ao final do estudo", porque não faz sentido, uma vez que toda pesquisa, pela legislação ética brasileira, deve ser gratuita, incluído eventuais benefícios diretos aos participantes.

Conclusões ou Pendências e Lista de Inadequações:

Aprovado.

Considerações Finais a critério do CEP:

Este parecer foi elaborado baseado nos documentos abaixo relacionados:

Tipo Documento	Arquivo	Postagem	Autor	Situação

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Continuação do Parecer: 3.290.555

Informações Básicas do Projeto	PB_INFORMAÇÕES_BÁSICAS_DO_PROJETO_1329291.pdf	06/04/2019 16:36:41		Aceito
Projeto Detalhado / Brochura Investigador	Projeto_detalhado.pdf	06/04/2019 16:03:57	HAIKO BRUNO ZIMMERMANN	Aceito
TCLE / Termos de Assentimento / Justificativa de Ausência	TCLE.pdf	06/04/2019 14:37:47	HAIKO BRUNO ZIMMERMANN	Aceito
Declaração de Instituição e Infraestrutura	Declaracao_da_instituicao.pdf	06/04/2019 14:30:05	HAIKO BRUNO ZIMMERMANN	Aceito
Folha de Rosto	folhaDeRosto.pdf	06/04/2019 14:29:34	HAIKO BRUNO ZIMMERMANN	Aceito

Situação do Parecer:
Aprovado

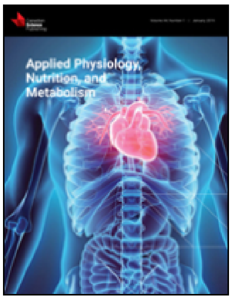
Necessita Apreciação da CONEP:
Não

FLORIANOPOLIS, 29 de Abril de 2019

Assinado por:
Nelson Canzian da Silva
(Coordenador(a))

ATTACHMENT B – ARTICLES

Home > Journals > Applied Physiology, Nutrition, and Metabolism > List of Issues > Volume 0, Number ja, > DOES POST-ACTIVATION POTENTIATION (PAP



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DOES POST-ACTIVATION POTENTIATION (PAP) INCREASE VOLUNTARY PERFORMANCE?

Haiko Bruno Zimmermann, Brian R MacIntosh, Juliano Dal Pupo

Published on the web 26 September 2019.
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Applied Physiology, Nutrition, and Metabolism, https://doi.org/10.1139/apnm-2019-0406

ABSTRACT

The transient increase in torque of an electrically evoked twitch following a voluntary contraction is called postactivation potentiation (PAP). Phosphorylation of myosin regulatory light chains is the most accepted mechanism explaining the enhanced electrically evoked twitch torque. While many authors attribute voluntary performance enhancement after a conditioning contraction (PAPE) to the positive effects of PAP, few actually confirmed that contraction was indeed potentiated using electrical stimulation (twitch response) at the time that PAPE was measured. Thus, this review aims to investigate if increases in voluntary performance after a conditioning contraction (CC) are related to the PAP phenomenon. For this, studies that confirmed the presence of PAP through an evoked response after a voluntary CC and concurrently evaluated PAPE were reviewed. Some studies reported increases in PAPE when PAP reaches extremely high values. However, PAPE has also been reported when PAP was not present, and unchanged/diminished performance has been identified when PAP was present. This range of observations demonstrates that mechanisms of PAPE are different from mechanisms of PAP. These mechanisms of PAPE still need to be understood and those studying PAPE should not assume that regulatory light chain phosphorylation is the mechanism for such enhanced voluntary performance. Novelty: -The occurrence of PAP does not necessarily mean that the voluntary performance will be improved. -Improvement in voluntary performance is sometimes observed when the PAP level reaches extremely high values. -Other mechanisms may be more relevant than that for PAP in the manifestation of acute increases in performance following a conditioning contraction.

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Dear Mr. Zimmermann,

Thank you for submitting your manuscript, PLYOMETRIC EXERCISE ENHANCE TWITCH PEAK TORQUE OF QUADRICEPS MUSCLES AND INDUCES SPRINT PERFORMANCE ENHANCEMENT IN ELITE TRACK AND FIELD ATHLETES, to European Journal of Applied Physiology.

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With kind regards,