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Theoretical Background and Practical Applications of the Physiological Mechanism of Post-Activation Potentiation

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Abstract

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Post-activation potentiation (PAP) is a mechanism that has gained interest in research during the past years. This is due to the fact that several studies use this physiological mechanism as a tool to improve athletic performance. This review will describe the basic principles of PAP and how exercise can influence the existence and magnitude of PAP. As definition, PAP is the phenomenon of increased force or twitch output that occurs after a high-intensity voluntary or evoked contraction. Although PAP is assumed to occur within the muscle due to the increased phosphorylation of the myosin light chains, several other factors can influence its appearance. The fact that fatigue counteracts the level of PAP, muscular as well as neural properties of the neuromuscular system contribute to the final outcome, despite the fact that PAP is mainly a mechanism that is attributed to changes in muscular level. During the past 5 years, our research group has examined in depth central and peripheral mechanisms that influence performance under the co-existence of PAP and fatigue. Numerous techniques combining the application of electromyography, electrical stimulation and force recording are briefly presented and discussed with emphasis on the practical aspect of interpretation on athletic performance. Using such techniques, some of the recent findings of our research group are presented, giving an insight in the PAP effect immediately after a contraction or after series of contractions and the effectiveness of long-term combined training programs.

© 2016 Published by Future Academy www.FutureAcademy.org.uk**Keywords:** Post-activation potentiation; physiology; isometric; training.

1. Introduction

Post-activation potentiation (PAP) is a topic of increased research interest during the past years and more recently has been more intensively investigated among the athletic research community as well. The phenomenon is rather complex and currently there is a significant body of literature that targets to explain its underlying mechanisms and to determine more precisely the range of applications that might have in human performance. Therefore, the purpose of this study is to analyse the basic principles of

PAP and its impact during exercise by analysing the factors that contribute to the PAP effect and eventually determine performance.

1.1. Definitions

Earlier studies have shown that after repetitive stimulation over a muscle the produced twitch torque increases for a short period of time after the end of the repetitive stimulation (Garnett, O'Donovan, Stephens, & Taylor, 1979). In this case the repetitive stimulation represents the *conditioning stimulus*, which in later studies has been replaced by an intense voluntary contraction with similar effects on twitch torque (Vandervoort, Quinlan, & McComas, 1983). The phenomenon of an increased production in twitch torque after an intense voluntary contraction is called *post-activation potentiation* or PAP, whereas when the conditioning stimulus is induced by electrical stimulation of high frequency rate the phenomenon is called *post-tetanic potentiation* (O'Leary, Hope, & Sale, 1997). The current study will cover issues regarding the PAP.

1.2. Possible mechanisms

Numerous authors attribute the phenomenon of PAP to the phosphorylation of the myosin regulatory light chains, in the presence of active myosin light chain kinase (Pääsuke, Ereline, & Gapeyeva, 1996; Rassier & MacIntosh, 2000; Sale, 2004). This phosphorylation increases the sensitivity of the released from the sarcoplasmic reticulum Ca^{2+} with the troponin-C (MacIntosh, 2003). This increases the level of cross-bridge formation for a given amount of Ca^{2+} release (Hodgson, Docherty, & Robbins, 2005; Sale, 2004). Furthermore, when Ca^{2+} bind to calmodulin, the myosin light chain kinase is activated, and the phosphorylation of the regulatory myosin light chains is catalysed (Manning & Stull, 1982). As a result, more ATP is phosphorylated, improving the formation rate of actin-myosin cross-bridge. Hence, the power output per cross-bridge is increased which might have a positive effect during explosive activities (Houston, Lingley, Stuart, & Grange, 1987).

1.3. Factors influencing PAP

The amount of PAP under different circumstances is affected by multiple factors (Tillin & Bishop, 2009; Xenofondos et al., 2010). Numerous conditioning stimuli have been tested for PAP in the past, varying for type of contraction and intensity, number of sets and repetitions. According to these studies there is consensus that the contraction should have maximum or near maximum intensity and that isometric contractions may induce higher PAP than dynamic ones (Rixon, Lamont, & Bembien, 2007). Furthermore, it should be mentioned that there is an accumulative PAP effect when repetitive conditioning stimuli are applied (Gossen & Sale, 2000; Tillin & Bishop, 2009). Furthermore, fast twitch (type II) muscle fibers contain more myosin light chain kinase and less of its antagonist myosin light chain phosphate than slow twitch (type I) muscle fibers (Moore & Stull, 1984). Therefore, muscles that contain higher percentage of type II fibers are prone to higher PAP (Hamada, Sale, MacDougall, & Tarnopolsky, 2000; Xenofondos, Patikas, Kocejka et al., 2014). Another factor that could affect PAP is the muscle architecture that might change after the conditioning stimulus. It has been reported 3-6 minutes after a maximal voluntary contraction the pennation angle decreased

(Mahlfeld, Franke, & Awiszus, 2004), which works in favour for force production. However, a more recent study did not verify this finding (Reardon et al., 2014).

As described in 1.2, PAP is a phenomenon that takes place on muscular level, and therefore it would be expected that events within the muscle milieu should be responsible for its expression. However, the conditioning stimulus does not exclusively result in the PAP effect, but induces fatigue as well (Sale, 2002). Fatigue and PAP act antagonistically and therefore, the measured muscle performance is the net result of the effect of both PAP and fatigue (Rassier & MacIntosh, 2000). For this reason, it could be argued that the final performance after a conditioning stimulus could be subjected to the effect of both peripheral-muscular and central-neural factors.

2. Research methods and results

There are numerous methods that are used from many research groups to investigate the function of the neuromuscular system. Many of them have been applied in the investigation of PAP as well and two of them, one for peripheral and one for central aspects, are shortly presented below.

2.1. Twitch torque

When a muscle is electrically stimulated the produced force that is transmitted to the tendons, bones and joints results in a measureable torque, the so-called twitch torque, which is independent of the volition and skill of the subject. Twitch torque properties are a milestone for the evaluation of PAP. The electrical stimulation can be applied over the muscle or the nerve that innervates the muscle or muscle group of interest. From the twitch torque numerous parameters can be evaluated, which describe several contractile properties of the examined muscles. Peak twitch torque is the maximum torque that the muscle can produce with a single stimulus and is related to the capacity of the muscle to produce force, which is a product of the muscle fibre diameter (Bowden & Goyer, 1960), the integrity of excitation-contraction coupling (Ingalls, Warren, Williams, Ward, & Armstrong, 1998), the activity of the myosin ATPase (Drachman & Johnston, 1973), and effectiveness of neuromuscular transmission along the neuromuscular junction (Fuglevand, Zackoaski, Huey, & Enoka, 1993). Time to peak torque and the rate of torque development (mean, maximum or over predefined intervals) are parameters that give information about the intracellular Ca^{2+} release kinetics (Harridge et al., 1996) and may be influenced by the elastic properties of the muscle-tendon unit as well (Winter & Brookes, 1991).

After a conditioning stimulus, studies have shown 9.2%-133.3% increase in peak twitch torque (Baudry & Duchateau, 2007; Folland, Wakamatsu, & Fimland, 2008; Gilbert & Lees, 2005; Hamada et al., 2000; O'Leary et al., 1997; Xenofondos, Patikas, Koceja et al., 2014) and 40%-135% increase in the rate of torque development (Froyd, Beltrami, Jensen, & Noakes, 2013; Gago, Arndt, Tarassova, & Ekblom, 2014; Gago, Marques, Marinho, & Ekblom, 2014; Shima, Rice, Ota, & Yabe, 2006). Moreover, in most of the studies time to peak along and half relaxation time decreased (Alway, Hughson, Green, Patla, & Frank, 1987; Hamada et al., 2000; Klein, Ivanova, Rice, & Garland, 2001; Krarup, 1977; O'Leary et al., 1997; Vandenboom & Houston, 1996). These changes in twitch torque indicate changes in Ca^{2+} kinetics, i.e. the rate of release from the sarcoplasmic reticulum and the

sensitivity to bind with troponin-C, as well as the rate of Ca^{2+} removal from the sarcoplasm (Hamada et al., 2000; O'Leary et al., 1997).

2.2. Hoffmann reflex (H-reflex)

The H-reflex is a technique used to examine the motoneurone excitability via the Ia afferent reflex pathway (Zehr, 2002). It can be affected by changes in the excitability of the motoneurone membrane (post-synaptic), and the excitability of the Ia afferent terminals (pre-synaptic). Therefore, changes in the H-reflex amplitude are explained by post-synaptic and pre-synaptic mechanisms, which are governed by central-descending commands and peripheral-sensory input (Schieppati, 1987). The H-reflex is evoked by low-intensity electrical stimulation over the nerve, which selectively stimulates the Ia afferent axons, which in-turn recruit the homonymous α -motoneurons. The muscle action potential which is recorded with EMG electrodes over the muscle represents the H-reflex, and the most common measure of it is the peak-to-peak amplitude (Zehr, 2002).

Potential of the H-reflex has been suggested as a possible mechanism contributing to PAP, since there are indications that, despite the small sample size, H-reflex is increased in the medial gastrocnemius muscle 5-13 minutes after a conditioning stimulus (Gülich & Schmidtbleicher, 1996). Nonetheless, according to other studies the contribution of such neural contribution on PAP appears to be conflicting (Folland et al., 2008; Trimble & Harp, 1998; Xenofondos, Patikas, & Kotzamanidis, 2014). According to the recent findings of our research group, it seems that H-reflex decreases immediately after the end of the conditioning contraction due to post-activation depression of the Ia afferents and recovers to the pre-conditioning values with no further potentiation within 1-3 minutes (Xenofondos, Patikas, Koceja et al., 2014).

3. PAP and human performance

The PAP effect on human performance has gained interest during the past years. Previous studies have used conditioning contractions targeting to enhance subsequent performance, especially in athletes. More particularly, they demonstrate an increase in performance for movements that demand power after several different conditioning stimuli such as a maximum isometric voluntary contraction (Tillin & Bishop, 2009), high intensity resistance training bouts (Tillin & Bishop, 2009), plyometrics (Tobin & Delahunt, 2014) or whole body vibration (Avelar et al., 2014). The positive effect of PAP was observed mainly in rate of force development, jump height and sprint time, but not in strength (Tillin & Bishop, 2009).

Although these results have been attributed to PAP and a recent study showed that in some extend PAP in twitch torque is correlated with performance enhancement (Nibali, Chapman, Robergs, & Drinkwater, 2013), it is questionable whether this could be the case. For instance, the gain in performance does not appear at the same time interval after conditioning stimulus as PAP appears when obtained by twitch torque measures. More specifically, twitch torque properties reach their maximal values directly after or within the first minute after the end of the conditioning stimulus, and thereafter the PAP effect gradually decreases (Hamada et al., 2000). On the contrary, in many cases

performance enhancement is not observed immediately after conditioning stimulus but after several minutes (up to 10 minutes, with optimum at ~5 minutes), when actually PAP effect is basically absent (Batista et al., 2007; Tillin & Bishop, 2009).

During and after a high intensity resistance training protocol fatigue and PAP coexist and compete out each other (Tillin & Bishop, 2009) and therefore a diminished PAP effect would be expected. Untrained subjects demonstrated that between sets, jump height occasionally increased and then decreased (Smiliotis, Pilianidis, Sotiropoulos, Antonakis, & Tokmakidis, 2005), while sprint time was not affected (Tsimahidis et al., 2010). In trained athletes, however, sprint performance between sets increased, underlying the importance of training background (Tsimachidis, Patikas, Galazoulas, Bassa, & Kotzamanidis, 2013). Regarding the potentiating effect after high intensity resistance training there are some studies that showed no effect in performance (Chatzopoulos et al., 2007) or increased performance (Gourgoulis, Aggelousis, Kasimatis, Mavromatis, & Garas, 2003), which indicates that further research in this field is recommended to be conclusive.

One plausible explanation for the discrepancy between PAP and performance is that voluntary execution of a movement is influenced by many more parameters than twitch torque. For instance although children and adults demonstrated similar PAP levels in terms of twitch torque (Pääsuke, 2000), children are not able to improve their jumping performance as adults do after a conditioning stimulus (Arabatzis et al., 2014). This indicates that deterioration in technique could mask the PAP effect, especially immediately after the conditioning stimulus when the fatigue effect is more prominent.

4. Conclusions

PAP is a complex phenomenon that is affected by events occurring on muscular level, but since it can be opposed to some extent by fatigue it may be influenced by neural factors as well. Despite the large number of studies, further research in a more targeted and controlled manner is required to explain more precisely relationship between PAP and human performance. Regarding performance, the maximal augmentation in athletic performance attributed to PAP is expected to occur when a conditioning stimulus or a series of conditioning stimuli have an optimal duration, intensity and rest interval that maximize the PAP effect and limit as much as possible fatigue, taking into account their accumulative effect that exists.

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