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POST-ACTIVATION POTENTIATION: FACTORS AFFECTING IT AND THE EFFECT ON PERFORMANCE

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Abstract
This review focuses on the factors effecting Post-Activation Potentiation (PAP) and its application in complex training. It was shown that the training level, the type of muscle fiber, the type of contraction, the duration of contraction, and the volume of contraction are factors which effect the duration and magnitude of PAP. It has also reported that PAP affects explosive activities such as jumping, sprint and upper body performance. Based on PAP complex training protocols were designed including in the same training session high resistance training and explosive movements which positively affected strength, jumping and running speed velocity.

Key words: Post activation potentiation, conditioning contraction, influence on performance, complex training.

1. Definitions

Post-Activation Potentiation (PAP) is defined as an increase in muscle performance after a conditioning contraction. The conditioning contraction could be a maximal voluntary contraction (Hanada et al., 2000), an evoked tetanic contraction (post tetanic potentiation) (Desmedt and Hainaut, 1968) or a series of evoked twitches (Sale, 2002). It has been shown consistently that such conditioning stimuli can increase twitch contractions, the rate of force development and the explosive movements. In this review, any potentiation in muscle force or rate of force development, will be referred to as post-activation potentiation (PAP), no matter how induced.

2. Mechanisms of post activation potentiation

Two principal mechanisms have been proposed to explain the phenomenon of PAP. The most plausible explanation for the potentiated state of muscle after maximal or near maximal stimulation is the phosphorylation of myosin regulation light chains (Paasuke et al., 1996; Rassier and Maclntosh, 2000; Sale, 2002). This mechanism is mainly attributed to actin-myosin interaction via Ca^{2+} released from the sarcoplasmic reticulum (Sale, 2002; Hodgson et al., 2005). Also, the myosin light chain kinase, which is responsible for making more ATP available at the actin-myosin complex that, in turn, increases the rate of actin-myosin cross-bridging. Hence, the maximum conditioning stimulus increases the power output of the cross bridges and this in turn improves the performance of explosive movements (Hodgston et al., 2005).

However, Tubman et al. (1996) examined the phosphorylation of the myosin light chain during post tetanic potentiation and concluded that this was not the only mechanism contributing to PAP. Another theory

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that has been proposed as an alternative mechanism is the increase in the recruitment of higher order motor units. (Chiu et al., 2003; Guillich and Schmidtbleicher, 1996).

Increased neural activity may occur through recruitment of more motor units, better synchronization of motor units, a decrease in presynaptic inhibition, or import more central nerve impulses (Aagaard, 2002;2003). There is also evidence to suggest that changes in pennation angle after the conditioning stimulus may contribute to PAP (Tillin et al., 2009).

Hence, the PAP may be the result of interactions between neural and muscular mechanisms that are not well understood at this time.

3. Characteristics of the subject

3.1 Training level

The training level seems to effect the presence and amount of PAP. Several studies have shown that trained athletes participating in a high level sport activities respond more to PAP than those who participate in recreational resistance training. (Schmidtbleicher and Buehrle, 1987; Gourgoulis and Aggeloussis, 2003; Young, 1993; Chiu et al., 2003).

The cause of this enhanced adaptation observed in trained athletes has been attributed to their ability to recruit motor units faster and at a higher firing rate in comparison to untrained individuals (Schmidtbleicher and Buehrle, 1987). Beside the ability of the motor neuron pool to tolerate higher activation frequencies, there might exist another adaptation phenomenon: trained subjects have more synchronized motor unit recruitment and therefore in a shorter time period a greater number of muscle fibers are contracting (Schmidtbleicher, 1984).

Gourgoulis and Aggeloussis (2003) found that the subjects with greater maximal strength showed a greater improvement in vertical jump after a conditioning stimulus (4.01%), than subjects with lower maximal strength (0.42%). Young (1993) speculated that stronger and more experienced athletes are subjected to less neural inhibition when lifting heavy loads and concluded that the combination of high and low intensities would be best utilized for athletes with a relatively sound strength training base rather than for beginners. Chiu et al. (2003) suggested that those subjects training at higher intensity would develop fatigue resistance as an adaptation of their intensive training regimens, and were more likely to realize PAP.

However, showing similar improvement in athletes with various force levels after evaluating the influence of strength in complex training to increase performance, it has been claimed that the training level does not affect PAP (Jensen and Ebben 2003).

3.2 Fiber – Type

Another property that effects PAP is the muscle fiber type and their distribution within a muscle which is determined primarily by genetic factors, but may also be influenced by age and activity level.The increased performance shown with PAP is evident in high intensity activities that require high force, speed and power. The performance in such activities depends on the amount of fast (type II) muscle fibers.

Studies with small mammals (Moore and Stull, 1984; Sweeney et al., 1993; Vandenboom and Houston, 1996; Braun and Loeb, 1998) and humans (Houston et.al. 1987; Hamada et al. 2000; 2003) showed that subjects with greater percentage of type II muscles fibers elicited a greater PAP response.

In humans, muscles with a higher percentage of type II fibers (e.g., gastrocnemius vs soleus) and people with muscles of higher percentage in type II fibers, exhibit greater PAP (Hamada et al., 2000). This is because fast fibers undergo greater phosphorylation of myosin regulatory light chains in response to a conditioning activity (Moore and Stull, 1984; Sweeney, 1993; Zhi et al., 2005).

3.3 Gender

There are a few studies which examined the differences in PAP between men and women. A study conducted by Jensen and Ebben (2003), indicated that although women produced lower maximum ground reaction force during jumping and did not jump as high as men, there was no effect of gender between repetitions.

Previous research examined the complex training effect with men and women first division basketball players with similar results between groups (Ebben et al., 2000; Jensen et al., 1999).
However, unlike other studies that found a significant improvement in men but not in women, non-statistically significant trend towards improvement in complex training jump performance was more pronounced in women than in men (Jensen et al. 2003). More specifically, before and after complex training, women jumped 0.56 m and 0.62 m, respectively, and men jumped 0.87m and 0.89m, respectively.

Finally, the results of the study of Jensen et al. (2003) suggest that the effect of complex training is similar for men and women athletes, and therefore PAP effects humans regardless of their gender.

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4. Conditioning contraction: type, duration, and volume

4.1 Type of contraction

Few studies have compared twitch potentiation characteristics after conditioning contractions induced by Percutaneous Electrical Stimulation (PES) versus Voluntary Contraction (VC) (Vandervoort et al., 1983; Binder-Macleod et al., 2002). However, it is difficult to compare the results of these studies because of different intensities of the conditioning contractions, and differences in the examined muscle groups and the electrical stimulation protocols.

However, there is one study which concludes that VC induces greater PAP than PES (Requena et al. 2008). More specifically twitch potentiation was greater during a VC than during a PES trial, immediately after the conditioning contraction and at 1 min of recovery. This difference in the magnitude of twitch potentiation disappeared completely at the third minute of recovery.

4.2 Duration of contraction

In human muscles, there is a general consensus that twitch potentiation is maximal immediately after a conditioning brief (5–10 s) isometric MVC (Hamada et al. 2000; Baudry and Duchateau 2004; Shima et al. 2006; Pääsuke et al. 2007) and declines exponentially over the time but is still evident for 5–20 min (Vandervoort et al. 1983; Hamada et al. 2000; Baudry and Duchateau, 2004).

4.3 Intensity of contraction

Results of studies (e.g., Vandervoort et al. 1983; Vandenboom et al. 1997; Brown and Loeb 1998) revealed that twitch potentiation was not observed during MVC trial.

Analysing the effect of conditioning VCs of different durations and intensities on twitch potentiation in human plantar flexor muscles it was concluded that VCs of less than 75% MVC produced little or no potentiation and that MVCs lasting 5–10s caused the greatest twitch potentiation (Vandervoort et al. 1983).

Keeping in mind the results of Vandervoort et. al. (1983), Baudry and Duchateau (2007) observed something unexpected: The potentiation of the twitch was observed after ballistic contractions which were performed at intensities as low as 20% of MVC. However, recent research of Requena et al. (2008), who investigated the twitch potentiation after voluntary versus electrically induced isometric contractions in human knee extensor muscles, reinforced the findings of Vandervoort et.al. (1983), since they found that a voluntary isometric contraction of knee extensor at 25% MVC was not enough conditioning stimulus to induce twitch potentiation, but immediately after the conditioning contraction, twitch potentiation was significantly increased only in MVC trial.

5. PAP and the influence on performance

For a brief maximal effort, like strength and speed performance, require all relevant motor units be recruited and fire at maximum possible rates. A little benefit could PAP offer when motor units are discharging at very high rates, because PAP cannot increase high-frequency force.

PAP increases work and power output (Grange et al.1993,1998) but in contrast, PAP does not increases the peak force of high-frequency tetani or the maximum unresisted shortening velocity (V max) of high - frequency tetani (Persechini et al. 1985) or the maximum velocity of unresisted maximal voluntary concentric contractions (Stuart et al.1988) .

In contrast PAP has an additional effect, even at very high stimulation frequencies where force is not increased by PAP, it can be increased the rate of force development (Vandenboom et al 1993). Also, PAP could increases the peak force by increases the twitch's rate of force development and decreases it's time to peak force (Grange et al.1993; Sweeney et al.1993). By increasing rate of force development and hence the acceleration attained with loads between zero (Vmax) and peak isometric force, increase the velocity attained with these loads. There are reports of improved performance in activities like jumping, running and throwing when the muscles were in a state of PAP (Radcliffe et al. 1996, Young et al. 1998).

5.1. Complex training and PAP

Coaches have applied the principles of PAP to training protocols in which heavy resistive exercises are performed prior to doing explosive plyometric exercises, referred to as complex training (Ebben et. al. 1997; 1998). It has been proposed as a way to improve the quality of the plyometric training stimulus. Verkhoshansky and Tetyan (1973) were the first to describe and investigate complex training and recommended performing plyometrics soon after the resistance training portion of the complex to take advantage of the possible heightened excitability of the central nervous system. These authors assessed the effectiveness of 16 weeks of training with complex pairs of exercises such as squats followed by jump squats on a set-for-set basis. They concluded that complex training group outperformed the other 2 groups.

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5.2 Jumping performance

Jumping exercises are often chosen because of their similarity to sports movements and because of their relatively low complexity.
Studies by Gourgoulis et al. (2003), Young et al. (1998) , and Gullich and Schmidtbleicher (1996) all used back squats involving various types of loading and rest periods to initiate PAP, and all of these methods appeared successful in eliciting PAP.

In a study by Gourgoulis et al. (2003) , in which each subject performed 5 sets of half squats with 2 repetitions at each of the following intensities: 20, 40, 60, 80, and 90% of the 1 repetition maximum (1RM) load. Prior to the first set and immediately after the end of the last set, the subjects performed 2 countermovement jumps on a Kistler force platform with primary goal to jump as high as possible. The results showed that mean vertical jumping ability improved by 2.39% after the warm-up period.

Young et al. (1998) found a 2.8% improvement in a vertical-loaded countermovement jump (LCMJ) performed 4 minutes after a heavy preload exercise of 5 repetition maximum (5RM) back squat.

Gullich and Schmidtbleicher (1996) investigated the effect of maximum voluntary contractions on subsequent power performance by having power athletes do countermovement jumps (CMJ) and drop jumps (DJ) before and immediately after maximum isometric contractions of the leg extensors. The post-isometric-contraction CMJ and DJ were significantly enhanced by 2.6 and 3.2%, respectively, compared with pre-isometric-contraction jumps.

Regarding the effect of the combined resistance and jumping performance it was found that it causes enhancement in strength level and all types of jumping squat, counter movement and drop jump). Resistance training per se, increases only squat jump in some cases while in other cases not (Gorostiaga et al 1999, Kotzamanidis Christos et al. 2005). According to relevant studies the reason for these differences was attributed to the specific muscle tendon unit adaptation. Specifically after resistance training only in the tendon an increase in stiffness observed (Kubo et al 2006). On the contrary after a complex training the stiffness of whole muscle tendon unit occurred (Kubo et al 2009).

The importance of complex resistance and jumping training could be underlined by the fact that its effect is extended not only to an integral jumping enhancement but to the other explosive movements such as kicking.

5.3 Sprint performance

Studies that have examined the influence of PAP on a repeated ballistic movement activity such as sprinting. Pfaff (1997) has reported that elite sprinters using protocol in which they performed 90% of their 1 repetition maximum (1RM) for 5 sets of 1 repetition of the back squat exercise with 2 minutes rest between sets and 20 minutes prior to competition, improved their sprinting performance

Smith et al. (2001) found that 5 min, three maximal 90% of 1 RM effort 5 sec maximal cycling velocity increased but this potentiation was diminished after 20m. Moreover, McBride et al. (2005) used a heavy-load squat (HS) protocol consisting of 1 set of 3 repetitions at 90% of the subject's 1 repetition maximum (1RM) and at 4 minutes post–warm-up, subjects completed a timed 40-m dash with time measured at 10, 30, and 40 m. The results of the study indicated that when preceded by a set of HS, subjects ran 0.87% faster in the 40-m dash (5.35 6 0.32 vs. 5.30 6 0.34 seconds) in comparison to Control group. The data from this study suggest that an acute bout of low-volume heavy lifting with the lower body may improve 40-m sprint times. However Chatzopoulos et al. (2007) found that that after ten maximal 90% of 1 RM trials both running acceleration and maximal velocity was increased. This fact indicates that possibly the number of trials affects the effect of PAP on ballistic performance

In a recent study by Linder et al. (2010), in which they consisted of a 4-minute standardized warm-up, followed by 4-minute active rest, 100-m track sprint, a second 4-minute active rest, a warm-up of 4RM parallel back half-squat, a third 9-minute active rest, finalized with a second 100-m track sprint. The results indicated that there was a significant improvement of 0.19 seconds , when the second sprint was preceded by a 4RM back-squat protocol.

Regarding the application of PAP in training planning related with the running performance the following studies were found. A combined program (Kotzamanidis et al. 2005) lasting 9 weeks consisting of 8-3 RM and 6 maximal 30 trials performed after resistance affected both jumping and running performance. In another recent study (Tsimahidis et al 2010) a complex resistance and running velocity program was designed. In this study which was lasted 10 weeks a maximal 30m trial was performed between 5 resistance sets 80-85% of 1 RM. The obtained results showed that acceleration, maximal velocity and all types of jumping (squat, counter movement and drop jump) were increased.

5.4 Upper-body performance

Hrysomallis and Kidgell (2001) examined the effects of a 5RM bench press on 3 separate explosive push-ups. The trial with the highest impulse, as measured on a force platform, was used for analysis. No

significant effects were observed for impulse, maximal rate of force development, or average and peak force output as a result of the preloading protocol performed 1.5 minutes prior to performance.
Also, Ebben et al. (2000) examined the effects of a 3–5RM bench press preload on 1 set of 5 medicine ball power drops (MBPD). No effect of the preload was found on the immediate subsequent EMG measures of the pectoralis major and triceps brachii or on maximal or mean vertical ground reaction forces. A similar study, using female subjects resulted in the same findings of no significant differences between the complex and non-complex training groups (Jensen et al., 1999).

However, unlike other studies, Evans et al. (2000), with subjects of 10 college age males with experience performing the bench press, performed a seated medicine ball put before and four minutes after performing the bench press with a 5RM load. Results indicate a significant increasein the medicine ball put distance of 31.4 cm following the 5RM bench press compared to the medicine ball put before the bench press.
So the PAP effect on ballistic movements of the upper limbs needs further research.

6. Conclusion

The purpose of this review was to examine the phenomenon of Post Activation Potentation and to analyse the factors that are effect it. The two principal mechanisms of PAP are the increased phosphorylation of myosin regulatory light chains and the increased recruitment of higher order motor units. Furthermore, in relation to the influencing factors and specifically concerning the characteristics of the subject, PAP is affected by the training background but not the gender of the subject. Furthermore muscles which higher proportion of type II muscle fibres tend to have more PAP.

On the other hand, PAP is effected by the conditioning contraction as well. Voluntary Contraction (VC) is more effective than the Percutaneous Electrical Stimulation (PES) and concerning the duration and the intensity of the contraction, we can conclude that twitch potentiation is maximal immediately after a conditioning brief (5–10 s) isometric MVC (>75%) and declines exponentially over the time, though it is still evident for 5–20 min.
Moreover, concerning the influence of PAP on performance there is evidence that while the force itself is not increased by PAP, it nevertheless increases the rate of force development. There are reports of improvement in activities like jumping, running and throwing when the muscles are in a state of PAP.
PAP is a research field that needs further investigation concerning the mechanisms that contribute to force output enhancement in human muscles in order to be able to transfer this knowledge to training of high performance athletes.

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