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POST-ACTIVATION POTENTIATION (PAP) IN SPORTS PERFORMANCE

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Abstract: The aim of this study is to compile and examine the existing knowledge on Post-Activation Potentiation (PAP). By analyzing the mechanisms of PAP, its effects on performance, and its role in sports applications in detail, the study seeks to contribute to the sports science literature. The relationship of PAP with fatigue, its integration into training protocols, and its impact on individual differences will also be addressed. The study aims to provide a basis for developing strategies to enhance athletic performance.
Research indicates that PAP has effects on performance parameters such as jumping, sprinting, strength, and endurance. The literature suggests that many of these effects vary depending on time. Studies show that the PAP effect is more pronounced in stronger individuals. In particular, plyometric exercises and less deep squat movements have been observed to enhance the PAP effect. This situation provides the necessary conditions for muscle fibers to generate potential more effectively. However, the functional importance and long-term effects of PAP are still not fully understood, and further research is needed in this field.

Keywords: Post-Activation Potentiation (PAP), Fatigue, Recovery, Training Strategies

Introduction

The continuity of force production is highly important for the success of movement. The ability of skeletal muscle to generate force depends on its training status and can be observed in athletes during acute activities. Differences among athletes in terms of fatigue, motivation, blood flow, and fiber composition can explain why previous activity may cause a reduction in force through neural and contractile responses.

The history of contraction may increase force output, which is defined as Post-Activation Potentiation (PAP). PAP is described as an enhanced contractile response to a given stimulus due to prior voluntary activation. The previous voluntary activation is referred to as a conditioning contraction. PAP is verified by measuring the increase in the amplitude of the contractile response following a conditioning contraction. The concept of PAP defines a phenomenon in which muscle performance acutely increases as a result of prior contraction events. PAP is therefore a physiological phenomenon that refers to an acute increase in muscle force production, and potentially performance, following a preload exercise [1].

The existence of PAP in skeletal muscles has been documented in numerous human studies. Recent reviews have sparked debate about the mechanisms of PAP and its application to sports performance. If used effectively, PAP can be applied within a strength training routine to enhance the training stimulus of plyometric exercise. Practicing PAP before competitions may improve performance in explosive sports activities such as jumping, strength, and sprinting, potentially offering greater benefits than traditional warm-up techniques.

However, due to inconsistencies in the literature, research has not yet reached a definitive conclusion regarding the potential benefits of PAP for explosive sports performance or training. These inconsistencies likely arise from the complex interaction of factors that affect acute performance following a conditioning contraction (CC).

Within this context, the aim of this study is to compile and review existing knowledge on Post-Activation Potentiation (PAP). By analyzing its mechanisms, effects on performance, and role in sports applications in detail, this study aims to contribute to the literature in sports sciences. The relationship between PAP and fatigue, its integration into training protocols, and its effects on individual differences will also be discussed. Ultimately, this study seeks to provide a foundation for developing strategies aimed at enhancing athletes' performance [2].

Method

Traditional literature reviews, either as standalone studies or as part of various research methodologies, involve the theoretical and contextual identification of existing knowledge on a specific topic or theme. The aim of this study was to investigate the role of post-activation potentiation (PAP) in sports performance. For this purpose, books, journal articles, meta-analyses, and systematic reviews available in the relevant literature were examined in detail. Databases such as EBSCOhost, PubMed, and Google Scholar were utilized for the literature search.

Mechanisms of PAP According to Harmancı et al. (2017), the literature refers to three physiological theories that explain the performance enhancement observed as a result of PAP:

1. Myosin Regulatory Light Chain Phosphorylation Theory: This theory suggests that prior stimulation leads to phosphorylation of the regulatory light chain of myosin, moving them away from the thick myosin backbone and closer to the thin actin filaments. At the same time, this process increases the sensitivity of the contractile apparatus to calcium ions (Ca^{2+}), thereby facilitating interactions within the sarcomere.
2. Neural Excitability Theory: This theory proposes that preload or preparatory exercises may enhance the excitability of synaptic junctions and spinal cord pathways, thereby contributing to increased force production.
3. Pennation Angle Theory: The third theory argues that an enhanced stimulus reduces the pennation angle within the muscle, allowing the force generated by muscle fibrils to be transferred more directly to the tendon. This results in increased strength and power output [3].

Phosphorylation of regulatory light chains (RLCs): The first theory suggests that following a conditioning exercise, there is an increase in the phosphorylation of myosin regulatory light chains (RLCs). This enhances the sensitivity of myosin–actin interactions, which may lead to an increased cross-bridge cycling rate. Such a change results in a rightward shift of the force – velocity curve, thereby allowing faster movements under heavier loads.

Understanding that PAP is similar to post-tetanic potentiation (PTP) is important for examining the role of both mechanisms in muscle force production and their effects on performance. The term "activity-dependent potentiation" can be used to describe all potentiation mechanisms based on muscle activation, including PAP and PTP.

A myosin molecule is a hexamer consisting of two heavy chains. Each heavy chain contains two RLCs at the amino-terminal region with specific binding sites for the incorporation of phosphate

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molecules. This mechanism is associated with myosin light chain kinase (MLCK), which is activated by an increase in intracellular free calcium ion [Ca^{2+}] concentration. This process alters the structure of the myosin head, moving it away from the thick filament backbone, thereby enhancing subsequent contractions [4].

The Ca^{2+} released from the terminal cisternae of skeletal muscle activates MLCK in parallel with the onset of contraction. This activation, through phosphorylation of the regulatory light chains, gives rise to PAP. The phosphorylated RLCs increase the calcium sensitivity of actin–myosin filament interactions. Consequently, this process contributes to stronger and more efficient muscle contractions.

Phosphorylation of myosin RLCs increases the mobility of myosin heads, thereby accelerating cross-bridge formation during muscle activation. This acceleration enhances force generation and efficiency, positively influencing overall muscle performance. The increased rate of cross-bridge formation further supports force development, highlighting the importance of these mechanisms in sports performance.

In conclusion, the greatest effect of RLC phosphorylation is observed at relatively low Ca^{2+} concentrations, such as during twitch or low-frequency tetanic contractions. This condition positively influences overall muscle performance by increasing force production and efficiency.

Increased recruitment of higher-order motor units (H-Reflex): The H-reflex, or Hoffmann reflex (also referred to as Hoffmann's sign or the finger flexor reflex), is a neurological examination finding elicited by a reflex test that can help confirm the presence or absence of issues originating from the corticospinal system. The Hoffmann reflex is a monosynaptic reflex and represents a reliable method for evaluating lower motor neuron function. Direct electrical stimulation of the tibial nerve induces a double twitch response in the soleus muscle. When the nerve is stimulated, compound action potentials (CAPs) are generated and travel in two directions along the motor fibers: downward toward the muscles and upward toward the spinal cord [5].

The second theory proposed to explain PAP suggests that several neurological mechanisms are activated following a conditioning exercise. Some of the neural responses observed after a conditioning contraction include H-reflex potentiation, increased motor unit synchronization, desensitization of alpha motor neuron input, and decreased reciprocal inhibition of antagonistic muscles. Among these, H-reflex potentiation appears to be the dominant neural mechanism.

The H-reflex is essentially an electromyographic (EMG) measurement of a muscle's level of excitability. Simply put, higher H-reflex amplitudes are associated with greater excitability. The H-reflex is the result of an afferent volley of nerve impulses produced in response to a single submaximal stimulus applied to the relevant nerve bundle. With adequate recovery, PAP increases H-reflex amplitude. This phenomenon is thought to result from the increased recruitment of higher-order motor neurons within the spinal cord.

Therefore, the increased involvement of higher-order motor neurons leads to faster and stronger muscle contractions, ultimately resulting in improved performance.

PAP and Mechanical Power

The performance of explosive sports activities is largely determined by mechanical power. Mechanical power is defined either as force (F) applied over a given displacement (d) within a specific time period (t) [$P = d/t$], or as the product of force and velocity [$P = F * v$] . Based on these definitions, increasing the level of force at a given velocity will enhance mechanical power.

Similarly, reducing the time over which a given force is applied - without changing the distance of force application-will increase velocity, and consequently, mechanical power. Therefore, PAP improves sports performance associated with mechanical power by increasing both the force and velocity of muscle contraction.

There is limited evidence to suggest that PAP increases maximum force output. The insufficient evidence aligns with findings that the increased sensitivity of the myosin–actin interaction to Ca^{2+} has little to no effect under conditions of calcium saturation caused by high stimulation frequencies (greater than 20 Hz for tetanic contractions or 200 Hz for voluntary contractions). For example, a 10-second isometric maximal voluntary contraction (MVC) of the knee extensors does not increase the maximum unloaded contraction velocity (or free contraction speed under no load) of subsequent dynamic contractions. This finding indicates that isometric contractions do not influence muscle speed in dynamic movements performed after a certain period [6].

Although there is general consensus regarding the existence of PAP, in order for it to be effectively utilized in performance and training, it must first be confirmed that PAP can be induced by either isometric or dynamic voluntary contractions. Subsequently, its benefits should be demonstrated in explosive sports activities. However, studies investigating the effects of PAP on performance in explosive sports remain inconsistent. Furthermore, little is known about the mechanisms through which PAP enhances neuromuscular responses.

How Does Rest Interval Affect PAP?

Conditioning exercises have been shown to enhance the neuromuscular system. However, these exercises are also known to induce a level of fatigue, as previously described by the fitness–fatigue model. This dual effect has been widely reported in numerous studies. One study found that immediately after a conditioning exercise, performance decreased, but after a recovery period of 4.5 to 12.5 minutes, a significant improvement in performance was observed. The researchers associated the initial performance decrease with fatigue. According to the fitness – fatigue principle, after approximately 12.5 minutes of rest, the potentiation effect diminishes and performance returns to baseline. Therefore, the correct rest interval is crucial for the effects of PAP to emerge. An appropriate rest duration may prevent fatigue from masking potentiation. Establishing an optimal balance between recovery and rest is essential for achieving effective results.

Numerous studies have investigated different rest intervals to determine which durations are most effective. However, there is no consensus among researchers on the optimal rest time. The lack of clear results in many PAP studies makes the issue even more complex. DeRenne recommended 8 - 12 minutes of rest, though difficulties in establishing a universal rest time are largely due to individual differences among athletes. Ultimately, every athlete has a unique recovery profile, and optimal rest intervals vary across populations [7].

It has been shown that trained athletes are more responsive to PAP effects than untrained individuals. Similarly, individuals with higher strength levels demonstrate greater sensitivity to PAP compared to those with lower strength levels. These findings highlight the importance of understanding the characteristics of the athlete population when aiming to maximize PAP benefits.

Furthermore, the type, intensity, and volume of the conditioning exercise can alter the extent of potentiation, as these factors directly influence fatigue levels. This complexity makes it challenging to provide precise training guidelines and complicates the decision-making process for strength and conditioning coaches.

While DeRenne suggested an 8 - 12 minute rest period, several studies reported that recovery times of 3 - 12 minutes can enhance performance.These findings represent only part of the available evidence. It may therefore be recommended that the most effective rest duration for benefiting from PAP lies within the 3 - 12 minute range [8].

In conclusion, rest intervals largely depend on the type of conditioning exercise performed and the athlete's training status (trained vs. untrained). Therefore, rest should be individualized. In this context, experts often apply the following general guidelines:

- 3 - 12 minutes of rest
- High intensity/heavy load (e.g., 90% 1RM) = longer rest
- Low intensity/light load (e.g., 30% 1RM squat jumps/plyometrics) = shorter rest
- High-volume sets = longer rest
- Low-volume sets = shorter rest
- Trained athletes = shorter rest
- Untrained athletes = longer rest
- Stronger athletes = shorter rest
- Weaker athletes = longer rest

Conclusion

PAP has been consistently shown to enhance subsequent athletic performances such as vertical jump (CMJ) and sprint. While conditioning exercises can improve performance, this effect is only evident once the initial fatigue subsides, as described by the fitness – fatigue theory. However, there is still no consensus on the optimal rest interval. Although rest periods of 3 - 12 minutes are currently recommended, they should be individualized according to the specific athlete. Exercise specialists must also consider the type, intensity, and volume of conditioning exercises, as these factors influence both the magnitude of fatigue and the extent of potentiation.

In general, biomechanically similar, high-load exercises (fewer than 10 repetitions, <10RM) provide the most effective PAP responses. Resistance-trained athletes are more sensitive to PAP effects and can achieve potentiation with shorter rest periods compared to untrained individuals. Research emphasizes that PAP responses are highly individualized, underscoring that there is no universal "one-size-fits-all" solution in exercise programming.

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