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**Review Article / Derleme**

# Beyond the warm-up: Understanding the post-activation performance enhancement

# *Isınmanın ötesinde: Aktivasyon sonrası performans artışını anlamak*

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**ABSTRACT**

This review explores the concept of Post-Activation Performance Enhancement (PAPE), a critical phenomenon in sports science that focuses on the acute improvement of muscular performance following high-intensity conditioning activities. PAPE has emerged as distinct from post-activation potentiation, with an emphasis on enhancing voluntary muscle performance rather than relying on twitch force assessments. This review examines the physiological mechanisms underlying PAPE, including neural factors and metabolic processes, and discusses the significance of these enhancements in various sports, particularly in activities requiring explosive strength and power. Additionally, it highlights practical applications for athletes and coaches, outlining how PAPE can be effectively integrated into strength and conditioning programs to optimize athletic performance across different populations, from elite athletes to elderly individuals. Despite its potential, PAPE's variability in response due to factors such as training history, genetic predispositions, and external influences, presents challenges for its practical implementation. Ultimately, this review offers a comprehensive overview of PAPE, its mechanisms, and its potential to enhance sports performance through evidence-based strategies.

**Keywords:** *Post-activation performance enhancement, acute improvement, conditioning activity, athletic performance*

**ÖZ**

Yüksek şiddetli aktivitelerden sonra kas performansının akut olarak gelişmesini ifade eden ve spor bilimlerinde önemli bir fenomen olan Aktivasyon Sonrası Performans Artışı (ASPA), aktivasyon sonrası potansiyasyon yöntemlerinden farklı olarak, yüksek şiddetli kas kasılmasının bilinçli olarak gerçekleştirildiği durumlardan sonra ortaya çıkmaktadır. Bu derlemede ASPA'yı etkileyen fizyolojik mekanizmalar ve bu mekanizmaların altındaki nöral ve metabolik faktörler açıklanmış ve bu faktörlerin özellikle kuvvet ve güç unsurları barındıran spor branşlarındaki etkileri incelenmiştir. Ayrıca, sporcular ve antrenörler için ASPA uygulamalarının önemi vurgulanarak, ASPA'nın elit sporculardan yaşlı bireylere kadar farklı popülasyonlarda atletik performansı optimize etmek için kuvvet ve kondisyon programlarına nasıl etkili bir şekilde entegre edilebileceği açıklanmaktadır. Tüm bunlara ek olarak, antrenman geçmişi, genetik yatkınlıklar ve dış faktörler nedeniyle kişiye göre değişen ASPA yanıtları ve uygulamadaki zorluklar bu derlemenin konusu olmuştur. Sonuç olarak, bu derlemede ASPA mekanizmaları açıklanarak kanıta dayalı stratejiler aracılığıyla spor performansını artırma potansiyelinin kapsamlı bir genel değerlendirmesi yapılmıştır.

**Anahtar Sözcükler:** *Aktivasyon sonrası performans artışı, akut etki, önkondisyonlanma aktivitesi, atletik performans*

## INTRODUCTION

In sport and exercise sciences, the pursuit of understanding and harnessing acute enhancements in muscular performance is a foundational endeavor. The significance of this is emphasized by the practices of coaches and practitioners who meticulously integrate pre-competition warm-ups to elevate neuromuscular performance (1-3). Warm-ups are traditionally believed to amplify performance through both temperature-related mechanisms, such as decreased resistance of muscles and joints, enhanced nerve conduction rate, thermoregulatory strain, augmented release of oxygen from hemoglobin and myoglobin, and expedited metabolic reactions; as well as non-temperature-related mechanisms, including increased blood flow, elevated baseline oxygen consumption, and psychological effects (1). Concurrently, the introduction of an added conditioning activity (CA) could potentially influence subsequent neuromuscular performance even beyond the effects of a standard warm-up (4, 5).

In both athletic and clinical contexts, the goal is twofold: to achieve both acute and chronic increments in physical function. While chronic improvements arise from long-term strategies like exercise periodization (6), acute enhancements are often the result of various physical or psychological strategies employed during or immediately preceding training sessions or competitions (7). Therefore, the concept of post-activation performance enhancement (PAPE), which is closely associated with post-activation potentiation (PAP), has received considerable attention

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within the field of sports science. This attention arises from its potential to improve athletic performance (8). In the realm of sport and exercise sciences, understanding the acute enhancement of muscular performance has profound implications for training, competition, and recovery strategies. PAP, as defined by Tillin and Bishop (9), is one of the fundamental concepts in this domain. They describe it as "the phenomena by which muscular performance characteristics are acutely enhanced as a result of their contractile history". However, the broad acceptance of this definition has not been without contention. In their publication, Tillin & Bishop (9) noted that the traditional understanding of PAP is closely tied to the use of a twitch verification test. Furthermore, PAP has been characterized as an enhanced muscle contractile response that occurs following an intense voluntary contraction. This response is measured via the maximum twitch force elicited by supramaximal electrical stimulation, as documented by Ramsey & Street and MacIntosh et al. (10, 11). Despite that, much of the research conducted in sports settings diverges from the strict parameters of twitch verification tests. Rather, many of those studies gravitate towards muscle power tests, such as vertical jumps. This discrepancy has led to misconceptions surrounding the actual potentiation responses (12).

The current literature on warm-up strategies and PAP reveals considerable variability due to differences in exercise type, load intensity, and execution, resulting in inconsistent findings. Ballistic exercises, which maximize force output and motor unit recruitment, are effective in eliciting PAP; however, improper execution parameters, such as delayed coupling time, can limit their efficacy. Timing remains critical, as the PAP effect peaks within 4 to 6 minutes post-stimulus, with emerging evidence suggesting a narrower optimal window between 28 seconds and 3 minutes (13).

Seeking clarity and distinction in this field, Cuenca-Fernández et al. (14) proposed a separate term: PAPE. While both PAP and PAPE emerge from a voluntary CA, their distinctions are pivotal. PAPE specifically pertains to enhancements in voluntary exercises, whereas PAP anchors its foundation in increasing force as seen during twitch verification tests. The nuance here is subtle yet significant: it's not uncommon for PAP and PAPE to be identified after identical CAs (14, 15).

PAPE is a phenomenon that leads to an acute improvement in power and strength performance due to the prior voluntary contractile history (16). It refers to the acute increase in explosive neuromuscular capacity experienced between 3–10 minutes after warm-up activities performed at maximal or near-maximal intensity(17). Studies have shown that PAPE can significantly enhance voluntary muscle force, with a different time course compared to other forms of potentiation (4). This enhancement is particularly relevant in activities requiring maximal voluntary effort, such as swimming and sprinting starts and sprint accelerations (18, 19). PAPE, highlighted in strength and conditioning training programs for its capacity to enhance strength and power performance (20), also aids in muscle strength and velocity development (4, 5). This contributes to heightened muscle power and reduced injury risk, even among elderly adults (20). The effectiveness of PAPE has been observed in various exercises, such as squats inducing enhancement in jumping performance (21), and resistance exercise affecting upper-body performance (22). Various warm-up protocols and exercise modes have been shown to affect the magnitude of PAPE, underscoring the significance of comprehending the impact of exercise range of motion on performance enhancement (23). Moreover, the enhancement of sprinting performance has been associated with PAPE, prompting investigations into the influences of different surfaces and training modalities on sprinters (24, 25).

Given the scope of this review, the term PAPE is more suitable and will be the primary focus. Hence the aim of this review is to explain the significance of PAPE for athletes, coaches, and sport/exercise scientists. Furthermore, to foster precision and optimize the practical application of PAPE protocols, this review will also discuss the applications used in literature with the aim of clearly outlining the CA, target exercise (i.e., performance test), and related topics.

**Historical Perspective**

PAPE has evolved as a concept distinct from PAP. It refers to the enhancement in voluntary muscular performance following high-intensity CAs without the classical confirmation of PAP through twitch force assessment (12). Evidence supporting the presence of PAP has been found in various scenarios. Metzger and colleagues (26) conducted a research study focusing on skeletal muscle fibers. They noted an increase in twitch potentiation within these fibers and attributed it to elevated state of myosin light chain phosphorylation. Other studies have explored the contractile properties of muscle twitches in subjects consistently observing enhancements such as increased twitch tension, faster tension development rates and shorter relaxation times after stimulation (27, 28). These investigations quantified PAP by analyzing the differences in twitch characteristics before and after stimulation.

explored PAPE in various contexts, such as trained athletes undergoing squat jumps and power push-ups after different activation protocols (29), and the impact of high-intensity flywheel resistance training on vertical jump performance (30).

The optimization of PAPE for explosive activities in competitive sports has been a subject of interest, with researchers seeking the most effective application methods (23). Additionally, investigations have been conducted on the effects of different exercise modes on PAP, highlighting the transient nature of skeletal muscle performance influenced by its contractile history (31).

Today, PAPE is a well-established concept in sports science and exercise physiology, with practical implications for enhancing athletic performance. The early stages of PAPE research, rooted in animal experiments, have paved the way for a deeper understanding of the physiological mechanisms underlying PAPE and laid the foundation for understanding the physiological responses of muscles to CAs and their subsequent impact on performance in humans (4)(See Figure 1).

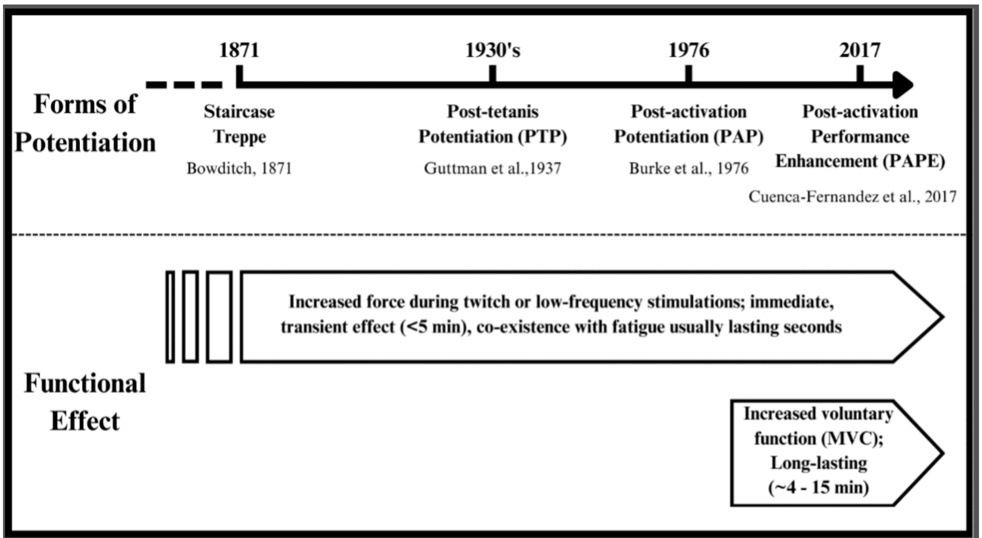


**Figure 1.** Visualization of the changes in different forms of potentiation over the years along with newly introduced terms and their functional effects. Redrawn from Blazevich and Babault (4)

**Mechanisms Behind PAPE**

Understanding the physiological mechanisms behind PAPE is crucial for athletes, coaches, and researchers seeking to leverage its effects for training and competition. There are certain fundamental physiological mechanisms that could lead to PAPE (32). One prominent theory suggests that PAPE is mediated by neural factors, such as increased recruitment of motor units and enhanced motor neuron excitability (8). Additionally, metabolic factors, including elevated levels of intracellular calcium and phosphorylation of key regulatory proteins, have been proposed to contribute to the enhancement observed after a CA (32). The precise interplay between neural and metabolic mechanisms in eliciting PAPE remains an area of ongoing investigation within the scientific community.

Phosphorylation of the regulatory light chain of myosin in conjunction with troponin-C results in increased sensitivity of calcium ion release from the sarcoplasmic reticulum, leading to an augmentation in actin-myosin cross-bridge formation upon calcium release (32). Following the calcium-calmodulin interaction, calcium ions promptly facilitate the activation of myosin light chain kinase. Activation of myosin light chain kinase enables the phosphorylation of the myosin regulatory light chain, which is presumed to cause the myosin head to move away from the thick filament towards the thin filament. Removal or reuptake of calcium affects the dissociation of calmodulin and the inactivation of myosin light chain kinase and potentiation ceases with the dephosphorylation of myosin regulatory light chain (4). Phosphorylation of myosin regulatory light chain and subsequent rotation of the myosin head result in an increased binding rate to actin, leading to an observed increase in force production (4). At submaximal calcium levels, this process enhances force production at a specific calcium concentration.

As a consequence of acute high-intensity voluntary muscle contractions, there is an increase in the number of motor unit recruitments and concomitantly in the firing frequency of motor units (9). Furthermore, due to the greater number and alterations in pennation angle affect the generated force transmitted to the tendon (9). Another physiological factor is the Hoffmann Reflex (H-Reflex), which encompasses proprioceptive mechanisms. According to the H-Reflex, preceding high-intensity acute voluntary muscle contractions lead to muscle spindle activation, resulting in increased firing of type Ia sensory fibers (32). This firing leads to increased excitability of alpha motor neurons and augmentation in the innervation of extrafusal muscle fibers (alpha-gamma co-activation).

In studies conducted on animals, it has been observed that an elicited tetanic isometric contraction (a condition causing the stimulation of specific afferent neural fibers, which in turn activates alpha motor neurons via afferent pathways) increases the transmission of stimulation potentials along synaptic junctions in the spinal cord (9). This phenomenon can persist in the minutes following contraction and lead to an increase in the same synaptic potential during subsequent activity (9). Indeed, this state of sensitive excitability can last for up to 20 minutes (33). In vivo observations have indicated that H-reflexes are often observed following maximal voluntary muscle contractions (34), although this phenomenon may not be consistently observed (4).

The pennation angle (the angle formed by the internal aponeurosis and fascicles) influences the force transmitted to tendons and bones; a smaller pennation angle confers a mechanical advantage in terms of force transmission to tendons (9). In the vastus lateralis muscle, the resting pennation angle was measured before and after maximal voluntary contraction, and it was determined that the angle measured 3-6 minutes after contraction significantly decreased compared to pre-contraction values (35). This alteration is thought to result in a 0.9% increase in force transmission to tendons, while also believed to influence the occurrence of PAPE.

**Factors Influencing PAPE**

Among the factors influencing PAPE, there exist biomechanical similarities between CA and performance activities (36-39), training history and strength level (40-43), the intensity of CA (44, 45), volume of CA (46) and the rest period between the CA and the expected change in performance of the subsequent movement (7, 47). Additionally, there are studies examining the relationship between sex and PAPE (48-50) (See Figure 2).

Studies have explored the effects of different CAs on PAPE, indicating that the type and intensity of the CA can influence the magnitude of performance enhancement (51). Different types of exercises, such as heavy resistance exercises, plyometric activities, ballistic and isometric exercises, can elicit varying degrees of PAPE (13, 20, 52, 53). The current literature on warm-up strategies and PAPE reveals considerable variability due to differences in exercise type, load intensity, and execution, resulting in inconsistent findings. For example, high-intensity CAs have been shown to cause localized PAPE in specific muscle groups (51). Additionally, the speed of movement during CAs, such as eccentric speed in front squats, can influence the responses of individual muscle groups to PAPE (54). Furthermore, the utilization of different strategies, such as intermittent voluntary isometric contractions, has been investigated to enhance the acute rate of force development (55) and improve performance outcomes (52). Fischer and Paternoster (55) investigated whether neural factors influence PAPE and whether mechanisms underlying PAP contribute to PAPE. While PAP showed a significant immediate increase in peak torque and rate of torque development two seconds after a conditioning contraction, no PAPE effects were observed at subsequent time points, regardless of whether contractions were voluntary or electrically stimulated. The results suggest that PAP mechanisms, such as myosin light chain phosphorylation, are unlikely to contribute to PAPE due to their short-lived nature, and no evidence for neural involvement in PAPE was found.

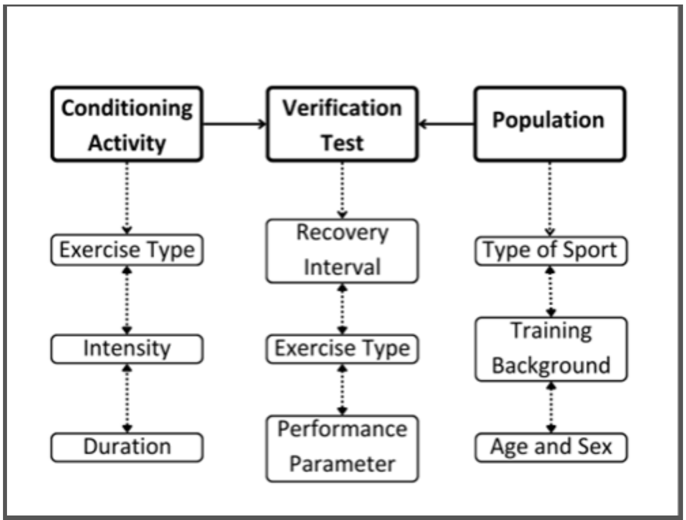


**Figure 2.** Factors influencing and moderating PAPE

Heavy resistance exercises have been found to induce significant PAPE effects, particularly in activities like the bench press throw (20). Plyometric exercises have also been shown to enhance PAPE, with studies demonstrating improvements in jumping performance following plyometric CAs (56). The specificity of the CAs to the subsequent performance task is crucial, as exercises that closely mimic the movement patterns of the target activity tend to produce more pronounced PAPE effects (14). The

The interchange of agonist and antagonist CAs has been recommended in resistance training to enhance post-activation performance in upper limbs, emphasizing the importance of exercise selection for specific outcomes (58). Moreover, researchers have explored the effects of resisted post-activation sprint performance enhancement in elite sprinters, demonstrating the potential benefits of incorporating resisted sprint CAs to enhance sprinting performance (24).

Higher-intensity CAs have been associated with greater performance enhancements compared to lower-intensity activities (59). For instance, studies have reported that performing heavy resistance exercises at intensities above 85% of one-repetition maximum (1RM) can lead to substantial PAPE effects in activities like the bench press throw (60). Studies have also delved into the impact of strength levels on adaptations to combined weightlifting, plyometric, and ballistic training, emphasizing the need for further research to understand how strength levels influence muscle activation and performance outcomes (61).

Moreover, the duration of the rest period between the CA and subsequent performance is critical. Optimal rest intervals allow for the potentiation effect to peak, typically occurring around 7-10 minutes after the CA (17, 29). The effectiveness of the rest period is influenced by factors such as muscle temperature, muscle fiber water content, and muscle activation levels (62). Additionally, muscle-specific factors like muscle fiber type, muscle temperature, and sarcomere length can affect the magnitude and duration of PAPE (52). The balance between potentiation and fatigue, as well as the specificity of the stimulus, and even genetic factors also play a role in determining the PAPE response (63, 64).

**Practical Applications**

Sport-specific applications of PAPE offer athletes in various sports the opportunity to enhance their performance through tailored CAs. Different sports require specific physical attributes and skills and utilizing PAPE strategies can be instrumental in optimizing athletic performance. In sports like track and field athletics, where explosive power and speed are crucial, athletes can benefit from PAPE protocols that focus on exercises such as plyometrics and sprint-specific CAs (56). By incorporating flywheel eccentric overload exercises, athletes can target muscle groups relevant to their sport and enhance sport-specific performance. Endurance sports, such as cycling and swimming, can also leverage PAPE to improve performance. PAP eliciting warm-up strategies have shown potential for enhancing performance in endurance events longer than sprints (65). By incorporating PAPE protocols into pre-competition strategies, endurance athletes can capitalize on the acute performance enhancements offered by PAPE, particularly in the initial stages of the event (66).

Team sports athletes can utilize PAPE to enhance sprinting and agility performance. Resisted sled sprinting activities can prime athletes for subsequent unresisted sprints, improving sprint performance in team sports. By incorporating heavy or very heavy resisted sled sprint-based CAs, athletes can optimize their sprinting abilities and overall on-field performance (67). Furthermore, sports that emphasize explosive movements, such as basketball and volleyball, can benefit from PAPE protocols that target vertical jump performance (68). Villalon et al. (68) examined the effects of PAPE on vertical jump performance in elite female volleyball players during competitive match conditions. The experimental group, which performed a squat-based activation protocol at 90% of 1RM, showed significant increases in vertical jump height immediately post-activation and maintained improvements until the second set of the match, while the control group exhibited delayed and smaller enhancements. These findings suggest that PAPE can enhance explosive performance when combined with a well-designed warm-up, though its effects diminish over time due to fatigue and other competitive factors. Moreover, implementing post-flywheel squat potentiation protocols can also enhance vertical jump and ground reaction force parameters, improving athletes' jumping abilities (69).

Strength and conditioning professionals can leverage PAPE to enhance neuromuscular responses, improve force production, and increase power output during training sessions. By incorporating PAPE strategies, athletes can experience immediate performance enhancements, allowing them to achieve higher levels of strength and power output during subsequent exercises (70). One key aspect of incorporating PAPE principles in strength and conditioning regimes is the selection of appropriate CAs. Utilizing high-intensity exercises that target specific muscle groups relevant to the subsequent performance task, athletes can maximize the potentiation effect and enhance their overall performance (20). Additionally, manipulating variables such as rest intervals and exercise intensity can further optimize the PAPE response and improve training outcomes (7). By strategically implementing PAPE protocols, athletes can enhance their bench press performance, increase muscle strength, and optimize training adaptations (30). Moreover, strength and conditioning professionals can utilize PAPE to enhance sprint acceleration performance, improve repeated sprint

**Table 1.** Effect sizes for different strength-power-potentiation complex components for both stronger and weaker individuals (Adapted from Seitz and Haff, 2015).

| | Stronger individuals | | | | Weaker individuals | | | |
|---|---|---|---|---|---|---|---|---|
| | ES | SD | 95 % CI | n | ES | SD | 95 % CI | n |
| **Type of CA** | | | | | | | | |
| Traditional high intensity | 0.54 | 0.35 | 0.40–0.68 | 26 | 0.34 | 0.53 | 0.12 to 0.57 | 24 |
| Traditional moderate intensity | 0.19 | 0.21 | 0.01–0.36 | 8 | 0.30 | 0.19 | 0.13 to 0.46 | 8 |
| **Squat depth of CA** | | | | | | | | |
| Parallel or below | 0.55 | 0.34 | 0.37–0.72 | 16 | 0.12 | 0.25 | 0.00 to 0.25 | 18 |
| Above parallel | 0.60 | 0.30 | 0.18–1.01 | 5 | 0.67 | 0.58 | 0.23 to 1.12 | 6 |
| **Recovery time post-CA** | | | | | | | | |
| 0.3–4 min | 0.15 | 0.16 | 0.06–0.24 | 15 | 0.28 | 0.25 | −0.12 to 0.67 | 4 |
| 5–7 min | 0.62 | 0.09 | 0.55–0.70 | 23 | 0.30 | 0.20 | −0.19 to 0.79 | 9 |
| ≥8 min | 0.34 | 0.21 | 0.13–0.52 | 6 | 0.36 | 0.38 | 0.12 to 0.56 | 17 |
| **Number of set(s) of CA** | | | | | | | | |
| Single set | 0.44 | 0.35 | 0.33–0.56 | 37 | 0.17 | 0.23 | 0.02 to 0.32 | 27 |
| Multiple sets | 0.57 | 0.18 | 0.49–0.64 | 23 | 0.49 | 0.58 | 0.16 to 0.81 | 20 |
| **Type of load during the CA** | | | | | | | | |
| Repetition maximum | 0.60 | 0.42 | 0.32–0.88 | 11 | 0.25 | 0.58 | 0.12 to 0.36 | 10 |
| Sub-maximal | 0.36 | 0.28 | 0.25–0.46 | 30 | 0.35 | 0.52 | 0.12 to 0.58 | 22 |

CA: conditioning activity, CI: confidence interval, ES: effect size, SD: standard deviation

## Potential Limitations and Concerns

Inevitably, there exist certain possible limitations and concerns regarding practical implementations of the PAPE approach. These restrictions are usually due to individual factors. Scholarly findings indicate that the diversity in individual responses to PAPE is complicated and shaped by a blend of factors including training history, genetic inclinations, and psychological aspects. Grasping these elements is imperative for strength and conditioning practitioners to customize PAPE strategies according to athletes' unique requirements, refine training methodologies, and maximize athletic performance with precision. For instance, trained individuals often exhibit a more pronounced potentiation effect compared to untrained individuals, as their neuromuscular system may be more responsive to CAs (53). In another study, applying three sets of three repetitions of heavy back-squat exercise as a CA did not acutely improve change of direction (COD) performances; on the contrary, COD performance was negatively affected due to the lack of resting time, with individual performance responses differing after two conditions for each athlete on COD tests, as few of the subjects benefited from the CA while most of the others did not (71). Furthermore, the role of external factors like caffeine ingestion or whole-body vibration in influencing PAPE outcomes is an area that warrants more research (72, 73). Exploring how these ergogenic aids interact with the mechanisms of PAPE and whether they enhance or diminish its effects can provide valuable insights for athletes and coaches.

In conclusion, while PAPE research has advanced our understanding of acute performance enhancement, there are still unresolved questions regarding its definition, optimization strategies, population-specific effects, and interactions with external factors. Addressing these ambiguities through further high-quality studies will contribute to refining training practices and maximizing the benefits of PAPE in athletic performance.

## Future Directions

Future studies should explore the existing knowledge gaps and emerging challenges related to PAPE. For example, investigating the impact of intracellular water levels on muscle force production, particularly in type II fibers, could provide a deeper understanding of how these factors contribute to enhanced muscle function following warm-up exercises. Additionally, examining the effects of intense exercise on muscle temperature, blood flow, and intracellular water accumulation may reveal their roles as potential contributors to improvements in muscle function and performance (4). The influence of increased muscle-tendon stiffness on muscle function is another area that warrants attention. Furthermore, the use of techniques such as muscle imaging, muscle-tendon stiffness measurements, and advanced biomechanical analysis could offer valuable insights into how muscle-tendon interactions affect force production during PAPE (4).

Assessing the effectiveness of specific CAs in enhancing athletic performance in scenarios where athletes complete comprehensive warm-up routines would be beneficial to bridge the gap between lab studies and real-world warm-up practices (74). Incorporating advanced technologies like electromyography (EMG), muscle imaging, muscle temperature monitoring, intracellular water measurement devices, and muscle activation sensors in research studies can offer a comprehensive understanding of the mechanisms and factors influencing PAPE. By leveraging physiological responses and neuromuscular adaptations associated with PAPE, leading to enhanced protocols for evoking and optimizing the PAPE response.

## CONCLUSION

PAPE represents a critical concept in sports science, enabling acute improvements in muscular performance through specific CAs performed prior to training or competition. While traditional warm-up routines have long been utilized to enhance neuromuscular performance through various mechanisms, the incorporation of high-intensity CAs offers additional benefits, leading to the development of PAPE as a distinct phenomenon of performance enhancement. Unlike PAP, which refers to force measured through twitch verification tests, PAPE focuses on voluntary exercises, underscoring the need to differentiate between these two concepts. The relevance of PAPE spans multiple domains within sports science, including strength and conditioning, injury prevention, and performance enhancement across diverse athletic activities. Its effects, lasting between 3–10 minutes post-activation, are observed through increases in muscle strength, power, and velocity across various exercises, making PAPE a versatile tool in optimizing athletic performance.

However, the practical implementation of PAPE is accompanied by challenges, as individual responses can vary widely due to factors like training history, genetic predispositions, and external influences. Further research is essential to refine PAPE protocols, focusing on the most effective CAs, rest intervals, and intensities for different populations, including elite athletes and the elderly. Additionally, deeper exploration into the neural and metabolic mechanisms underlying PAPE can inform the development of targeted interventions to maximize its benefits. Investigating the interactions between PAPE and external factors such as nutritional interventions and recovery strategies also holds promise for optimizing performance enhancement. Advancing our understanding of PAPE through continued research will not only clarify its physiological foundations but also contribute to the development of evidence-based strategies to enhance athletic performance across various sports and populations.

***Conflict of Interest / Çıkar Çatışması***

The authors declared no conflicts of interest with respect to authorship and/or publication of the article.

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