Title: The Utilisation of Post-Activation Performance Enhancement to Enhance Jump Performance during Training and Sporting Competition

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ABSTRACT

Post-activation performance enhancement (PAPE) may be used to enhance jump performance. The review recommends PAPE can be subcategorised into two groups: Training PAPE and Performance PAPE. Training PAPE methods can be incorporated for training purposes where more select equipment, time, and space is available. Performance PAPE can be utilised to enhance competition performance in which limited, or no equipment, is required and can be easily performed before an event. This review highlighted that isoinertial methods are commonly employed for both performance and Training PAPE; however, plyometric training appears a more favourable form of Performance PAPE. Furthermore, accentuated eccentric loading could be coupled with plyometric training to achieve the highest PAPE response, but further work is required.

Key Words: Enhanced Neural Drive; Conditioning Exercise; Plyometric Training; Isoinertial; Accentuated Eccentric Loading.

INTRODUCTION

Jumping is a key determinant of successful performance within various sports (i.e., the jump in a long jump, the take-off in swimming, etc (13,33)). Hence, research has been conducted to enhance jump performance for both training and competition (31). For example, increasing jump performance can be achieved via developments in muscular strength which may lead to improvements in metrics such as jump height and impulse strategy (27).

Including a high-intensity exercise during a warm-up has the potential to elicit an acute increase in jump performance (8) and is a phenomena commonly referred to as muscle potentiation (2,12,21,24). Following exercise, fatigue and potentiation coexist,

though fatigue dissipates at a faster rate leaving a window of opportunity to exploit potentiation and enhance subsequent exercise performance (21,22,24,40). Post-activation potentiation (PAP) applies to this concept by performing a conditioning exercise (CE) which typically involves a heavy loaded exercise (>85% one repetition maximum (1RM)) or a low to moderate load, high velocity exercise prior to a ballistic or plyometric exercise. The rationale behind this is to evoke a higher neuromuscular response during the ballistic or plyometric exercise; however, a suitable rest period must be prescribed between the two exercises (1,21,22,39,42,47). This enables the fatigue to dissipate to maximise the performance of the ballistic or plyometric exercise (9,21,22). However, PAP has been known to be individualised and the subsequent response can differ between specific groups (i.e. strength levels and training experience) (28). Whereby, individuals who attain greater strength levels such as 1.5-2x bodyweight (BW) back squat can recover quicker than individuals who are seen to attain lower strength levels <1x BW back squat, thus, allowing for a quicker recovery time between the CE and subsequent main activity.

Within the literature, PAP has commonly been misunderstood. Recently Blazevich and Babault (5) reviewed the history and mechanisms associated with PAP. Further reference was made to a new construct, post-activation performance enhancement (PAPE). Briefly, PAP is defined as an enhanced muscle contractile response for a given level of stimulation following an intense voluntary contraction, which is measured as the maximum twitch force evoked by supramaximal electrical stimulation (5). It was argued that practitioners often reported an enhancement involuntary muscle force or power following CE, without confirmation of twitch stimulation. As such, many investigations fail to establish whether performance enhancement is from the mechanisms which underpin PAP or are a result of other factors that impact muscle function, such as temperature, activation, etc. Therefore, PAPE was proposed to delineate the phenomena and ensure practitioners are implementing methods cognisant of the correct underpinning mechanisms.

The mechanisms responsible for eliciting high levels of muscle potentiation during PAP and PAPE are yet to be fully elucidated. Nonetheless, the key mechanism responsible for PAP is the phosphorylation of myosin regulatory chains (5). In contrast, PAPE mechanisms are typically associated with increased muscle temperature, muscle water concentration, and an enhanced neural drive which subsequently, enhances rate of force development (5). However, the underpinning PAP and PAPE mechanisms are yet to be fully

understood. Though, the acute enhancement in neural drive is of specific interest to strength and conditioning (S&C) coaches as there is potential to have improvements in exercise performance. Inevitably, this will lead to more effective training time with athletes being able to achieve a greater training stimulus. Logically, if there is a larger neural stimulus individual could perform exercises with a greater force production and subsequently lift greater masses or execute exercises at faster velocities. However, this needs to be researched to determine if this concept would allow for greater adaptations.

There is currently a lack of consensus regarding the application of PAPE to improve jump performance. This appears to be down to studies including a wide variety of CE's, loading methods, rest periods and participants (13,26,37), making it difficult to draw definite conclusions. Previous investigations have noted that optimal rest periods are between 2 and 20 minutes (6) and that both heavy strength training and plyometric exercises can be used to improve performance (30,38,46). While many of these investigations provide an application to sporting performance, the majority also rely on specific equipment which may be difficult to obtain within training and/or pre competition settings. This may explain why practitioners are somewhat reluctant to include PAPE in training and performance settings. Therefore, the purpose of this review was to assess past and current literature to establish which PAPE methods can be utilised during training and before a sporting event to better understand the application of PAPE.

Mechanisms of post-activation potentiation and post activation performance enhancement

PAP includes a CE and aims to evoke muscle potentiation that is used to increase subsequent exercise performance by means of increasing muscle twitch force. The enhancement of muscle electrical potential is thought to explain the increase in muscle twitch force and may be apparent for up to one minute following the CE (6,12,39). A PAP response is typically observed following a maximal or near maximal muscle action, with the phosphorylation of myosin light chains explaining much of the improvements in performance. Upon an influx of calcium, the myosin light chain kinase activates the myosin head, causing it to rotate away and toward the actin filament, which in turn, increases cross-bridge formation (5,29). The myosin light chain kinase interacts with the regulatory light chains within the myosin molecule of actin and myosin (2,19,29) which modifies the myosin structure to a state of force production.

In contrast, PAPE incorporates a CE which is thought to potentiate the muscle via an increase in maximal voluntary contraction (MVC). The potentiated state of PAPE is thought to peak after 7 to 10 minutes which is more condensed than PAP (2 to 20 minutes) (20). This could be achieved via a few different physiological mechanisms such as; an increase in muscle temperature and an enhanced neural drive (5). An increase in neural drive is believed to increase maximum force production and rate of force development which occurs due to an augmented spinal-level excitability (5). This increase in neural drive is proportional to a reduction in transmitter failure at the synaptic junction, which subsequently increases muscle unit recruitment. It is this higher muscle recruitment which would allow for an increase in areas such as maximal force production. The aforementioned physiological processes of how PAP and PAPE are achieved, indicate two subcategories that allude to a specific timeframe in which the potentiated state of muscles will range from. Additionally, it highlights the mechanisms that could be allocated to muscle potentiation after a CE is performed. For further insight into PAP and PAPE, please see Blazevich and Babault (5) which provides a comprehensive review of the potential mechanisms underpinning PAP and PAPE.

How post activation potentiation can be implemented to enhance sporting or training performance

Similar to PAP, S&C coaches will typically employ complex training, whereby a heavy resistance exercise is performed prior to a power-based movement, e.g. heavy back squat to enhance vertical jump performance (23,32). Though the utilisation of PAPE to enhance jump ability in sport has shown promise, the procedure itself lacks clarity as to whether it should be utilised in training or competition. The limited use of PAPE in practice could therefore be because of the aforementioned confusion (6). Indeed, if different approaches to PAPE can be designed in line with training and performance purposes, perhaps its incorporation into performance may be amplified (3). Hence, the authors suggest that PAPE should be separated into two groups: “Performance PAPE”, and “Training PAPE”. The difference between the two groups is that Performance PAPE is a method that can be completed before a sporting event, in which limited equipment is needed, and can be easily performed in any environment. An example may include plyometric training (9).

Contrary to Performance PAPE, Training PAPE will incorporate methods more appropriate

to an individual's training environment, whereby more equipment is available. This may include barbell back squats to enhance jump performance within an S&C room or sled pulls to improve sprint performance during field-based training (6). Complex training can prove advantageous, though, the need for external equipment is paramount to its success and this is unlikely to be possible immediately prior to sporting events (3). Nevertheless, it could be incorporated into Training PAPE, whereby the equipment needed is more likely to be available. It would therefore be within an S&C coaches' discretion whether their method of PAPE is to be performed during training, or to enhance sports performance.

Post activation potentiation as a means to enhance sporting performance

The application of PAPE to enhance a power-based movement has been frequently investigated throughout literature (8,23). As previously mentioned, numerous populations have been analysed with a large variance in athletes which show promise to enhance power-based exercises. However, one major concern is the practical application and where specific training procedures, or sports fit a modality of Training PAPE or Performance PAPE.

As can be seen in Figure 1, it is vital that S&C coaches consider the key questions noted to understand which PAPE procedure best fits their practice. Hence, Figure one can be used to guide S&C coaches when deciding upon the specific PAPE method they wish to apply amongst their athletes. The description provided outlines the key areas to consider if a PAPE procedure is applicable to the athletes and the sport.

When analysing sports such as rugby and football, Performance PAPE methods may be difficult to utilise unless plyometric based motions are incorporated. Logistically, it is extremely difficult to perform a complex training method as a high number of players need to perform an exercise at various loads, which is further complicated by inter-individual differences in optimal time periods. Additionally, during these types of sports, event duration differs significantly and numerous movements occur, therefore, impacting potentiation (2) and likely making Performance PAPE surplus. However, applying Training PAPE to these scenarios could be seen as beneficial and applicable. Alternative sports such as athletics and specifically, the long or high jump and swimming events

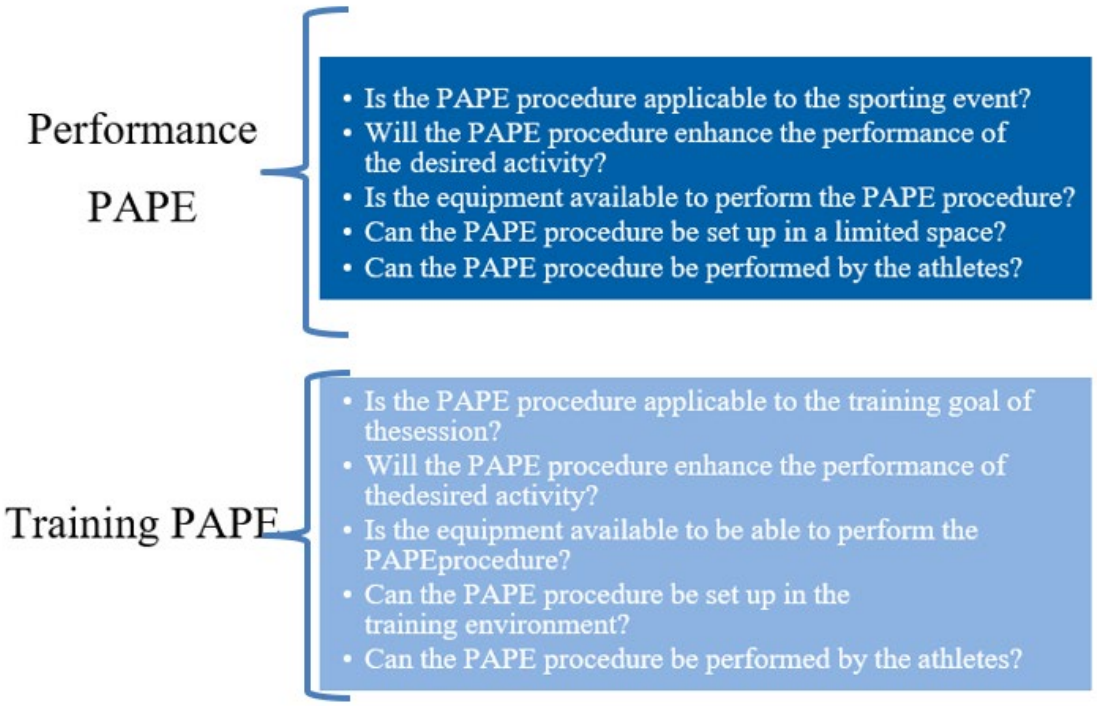

Figure 1 A guide for the implementation of Performance PAPE and Training PAPE.

which begin on a diving block (i.e., front crawl, breaststroke, and butterfly) appear to be better suited to both Performance PAPE and Training PAPE. For example, all of these sports require a jumping task which is performed at the very beginning of or shortly after the event starts. Thus, PAPE is more likely to play a role in the performance of such events when compared with rugby or football. Here, the athlete may spend considerable time walking or jogging before a task that could benefit from PAPE occurs, after which potentiation will likely have subsided.

Isometric and isoinertial conditioning exercises

A crucial consideration when looking to incorporate a PAPE protocol is the CE, that is, the CE must bear similarities to the subsequent exercise to maximise the potential for performance enhancement to occur. A common debate between researchers is the type of muscle action and sequences that should be used during the CE (28). For example, many suggest that an isoinertial exercise is best suited to improve performance whereas others argue that isometric exercise is superior. Isometric exercises can be seen as a suitable approach as the athlete is required to perform a maximal voluntary contraction (MVC). Batista et al (3) utilised 1 and 3 repeated 5-second hold on leg press to enhance jump performance, though, trivial effect sizes (<0.08) for all groups were observed. Berning et al

(4) assessed a 150% of 1RM isometric front squat to enhance jump performance with their results demonstrating that the trained subjects showed improvement of 5.5% in jump height after the isometric squat CE. Typically, isometric type exercises involve either using equipment such as isometric dynamometer, barbells, or that of leg press and therefore, this method can be excluded as a Performance PAPE procedure. Additionally, using equipment such as a leg press for isometric exercises would again only be useful if the sporting facility has one. Furthermore, extensive loads would need to be used as during an isometric contraction (4). However, some of this equipment would be available in a training facility and, therefore, could be used as a means to enhance jump performance via training PAPE.

Isoinertial methods seem a more applicable training procedure to utilise for both Training PAPE and Performance PAPE. This combination of eccentric, isometric and concentric muscle actions bear greater similarities with jumping actions and could be seen as a more effective method. This links to the theory of dynamic correspondence, in which training should target similar movement patterns and force vectors that are performed in the sport (27). This logic stems from if an exercise simulates a sporting motion there is potential that the sporting motion could be enhanced such as execution duration or greater control. Researchers (15,25,28) have assessed this approach to PAPE, with the back squat being the most frequently used CE. For example, Gahreman et al (15) observed an improvement in repeated jumps following a back squat and deadlift CE, though the back squats led to the largest potentiation effects ($d = 0.34$). In order to perform these types of exercises at sporting events, equipment is needed with the added necessity for weights to allow for appropriate loads. Therefore, unless practitioners can find means to apply it in a sport setting, this method should be excluded for Performance PAPE, however, it could be beneficial as a Training PAPE protocol. Alternatively, plyometric training could be seen as a means for PAPE as very little or no equipment is needed (26). Sharma et al (26) indicated that plyometric based training should produce a greater PAPE response than that of a heavy back squat via a % and plyometric based training achieving 13% increase and a significant increase when compared to the back squat (3.7% increase). However, Pagaduan et al (22) review's contradicts this finding in that the heavy back squat achieved a greater PAPE response than that of plyometric exercise. Nonetheless, given the wealth of findings in support of PAPE using plyometric exercise, with improvements comparable to heavy resistance-based exercise (17,23,33), it is suggested that CE's incorporating plyometric exercise can be used for both Training PAPE and Performance PAPE.

Another component to consider is the velocity of the CE and more specifically the acceleration during the eccentric phase of an exercise. Force is equal to that of mass x acceleration (f= m x a) (31); however, there is reduced research comparing fast velocity traditional methods. This can be seen in various PAPE studies, whereby, a heavy resistance exercise was performed before a power-based movement. Yet, if an object is travelling at a greater velocity then its kinetic energy and momentum will both increase (30,31). If an object has greater momentum, then it would need a larger force to decelerate and stop the object ensuring that time duration of the eccentric phase remains the same, therefore, employing a greater impulse strategy (impulse = force / time) (16,31). This observation can be utilised with that of PAPE and the incorporation of resistance bands. Resistance bands would allow for an increase in acceleration because they apply the mass of interest with an additional force (Fappiled = Fmass + Fband) (1,14). Where Fmass is the mass of the object that is applied with by gravity (i.e barbell load) and Fband is the load that is applied by the bands (1,14). The incorporation of bands could result in less load being needed so that PAPE could be achieved among athletes, however, band tension is difficult to quantify, and a practitioner would need a suitable place to anchor the bands. Therefore, more research regarding PAPE protocols using resistance bands is warranted before a conclusion can be made.

The effects of eccentric phase execution on post activation potentiation response

Interests in eccentric training among researchers and practitioners have grown significantly in the past decade. This is likely because an individual can lift approximately 50% more during eccentric muscle actions compared with concentric muscle actions (8,23). In fact, this capacity to produce more force is coupled with the ability to do so at greater velocities. Furthermore, eccentric muscle actions have been shown to have a less metabolic cost than that of concentric muscle actions (18). It has been theorised that maximal eccentric actions allow for type IIx fibres to be acutely enhanced (10,11). Though, maximal eccentric actions are usually performed with a method such as supramaximal accentuated eccentric loading (AEL), however, this is likely to fatigue the athlete and is equipment dependent i.e., weight releasors. However, instead of viewing increased loads, by increasing eccentric velocity a similar or greater response than supramaximal AEL could be achieved. Thus, activating type IIx muscle fibres it is therefore likely that overloading or increasing the velocity of an eccentric muscle action during a CE could result in similar or greater potentiation compared to traditional PAPE.

Employing methods such as eccentric only or AEL seems plausible for use in practice. For example, following the inclusion of eccentric loading and AEL, acute studies have noted an increase in force production during the eccentric phase that led to an enhancement in the concentric phase (18,19,23). Although it could be suggested to provide benefits to PAPE, research in this area has typically investigated supramaximal loads which have led to improvements in force production (19,45). However, as mentioned previously, prior to sporting performance and training it is unlikely that athletes would have access to appropriate equipment. However, it must be noted that increased eccentric loading during exercises can lead to increase damage when compared to concentric actions.

Seitz and Haff's (25) highlight that plyometric exercises could elicit a greater response than resistance based training for PAPE response. However, others have looked to combine plyometrics and AEL, with Handford et al (16) establishing the term Plyo-AEL. Unlike supramaximal AEL and heavy resistance-based exercises, a plyometric based AEL exercise could be utilised pre-competition, e.g., a drop jump could elicit high forces that are essential for potentiation to occur. Hughes et al (18) and Bridgeman et al (7) both employed a drop jump with the addition of adding two dumbbells during the eccentric phase of the landing and releasing them prior to the concentric phase to increase eccentric load. Hughes et al (18) found that jump height was increased when compared to that of the bodyweight jump; however, only jump height metrics were shown during this study and therefore, impulse strategy may have factored these results. Impulse can alter performance as if subjects performed a longer ground contact time during the PAPE method, this may have acutely enhanced jump height and not that of the PAPE method (20). The combination of AEL and plyometric exercises, especially the drop jump exercise poses an interesting method that can be easily performed before a sporting event (13). More specifically, this may entail the use of dumbbell or elastic-banded AEL drop jumps. During drop jumps higher forces can be achieved but with the addition of AEL a larger eccentric force could be achieved (6,13).

PRACTICAL APPLICATION

In future research, it is recommended that authors could start addressing the application of their PAPE method to either be employed for training or performance purposes. The idea of categorising methods into 'Training PAPE' and 'Performance PAPE' seems advantageous to both practitioners and academics, as this would allow for real-world constraints to be

Figure 2 Accentuated eccentric loading (AEL) countermovement jump (CMJ) which employed a handheld band release method., A: beginning of the jump, B: unweighing phase, C: braking phase and release of the AEL load, D: propulsion phase.

considered allowing a better understanding of which method best suits a training or performance purpose. Isometric, isoinertial and eccentric methods are suitable to be employed during Training PAPE; however, jumping based movements can be employed for Performance PAPE due to their simplicity. The incorporation of Plyo-AEL could allow for greater forces to be achieved and be easily applied before a performance event. An example of real world setting for both Training PAPE and Performance PAPE can be seen in figure 3.

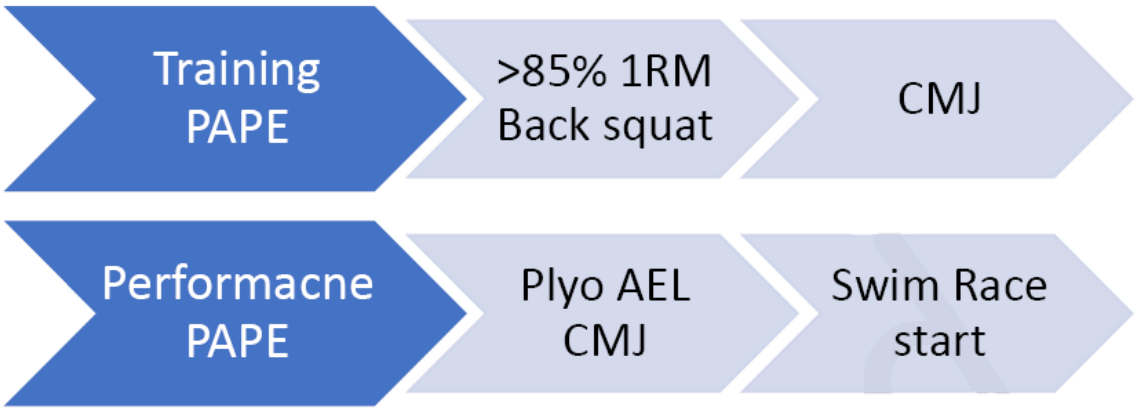

Figure 3 Visual example of how Training PAPE and Performance PAPE can be implemented into training and competition.

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