# A new taxonomy for post-activation potentiation in sport

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# A New Taxonomy for Post-activation Potentiation in Sport


## Abstract

Post-activation potentiation (PAP) mechanisms and responses have a long scientific history. However, to this day, there is still controversy regarding the mechanisms underlying enhanced performance following a conditioning activity. More recently, the term post-activation performance enhancement (PAPE) has been proposed with differing associated mechanisms and protocols than with PAP. However, these two terms (PAP and PAPE) may not adequately describe all specific potentiation responses and mechanisms and can be also complementary in some cases. **Purpose:** this commentary presents and discuss the similarities and differences between PAP and PAPE, and subsequently elaborates on a new taxonomy for better describing performance potentiation in sport settings. **Conclusion:** the taxonomy elaborated proposes the formula "Post- [CONDITIONING ACTIVITY] [VERIFICATION TEST] potentiation in [POPULATION]". This taxonomy would avoid erroneous identification of isolated physiological attributes and provide individualization and better applicability of conditioning protocols in sport settings.



**Key Words**: post-activation performance enhancement; post-activation potentiation; post-tetanic potentiation; power; strength.

## Introduction

Post-activation potentiation (PAP) is a muscular phenomenon which consists of an acute increment in strength and power performances as a result of the recent voluntary contractile history.[1] Much of the past literature suggested that PAP-induced augmented power contributed to enhancement of sport-specific tasks such as explosive jumps, sprints, changes of direction, and throws.[2,3] Many different conditioning activities have been used by coaches and researchers to induce subsequent performance enhancements, including resistance,[4] ballistic,[5] and flywheel[6] exercises. The primary mechanism underlying PAP is the phosphorylation of the myosin regulatory light chain (MLC), a peripheral muscle memory mechanism, which leads to greater peak force and rate of force development (RFD)[7]. Thus, PAP has traditionally been considered one the main objectives during warm up routines.[8]

The role of PAP on sports performance has been recently debated with the proposal of an alternative term, referred to as post-activation performance enhancement (PAPE).[9] The reasons behind this dualism (PAP vs. PAPE) refers to the association of PAP with evoked twitch verification which, in turn, would be related to MLC phosphorylation, during a very short period of time (<5 min). Conversely, PAPE would be associated with increases in voluntary performance primarily as a consequence of other potential mechanisms (e.g., temperature, water content), over longer time windows (>5 min).[10] While we believe this recent proposal has merit and could shed light on current practices and further studies, we also suggest that this dualism could limit physiological interpretations. That is, the physiological mechanisms underlying an acute effect of a conditioning activity may not be always revealed by the selected test. This does not necessarily mean the inexistence of a physiological effect, but an inadequate signal-to-noise ratio to detect these changes. This fact would better explain the inconsistent results when simultaneously assessing jump performance and twitch verification,[11] which represents a serious limitation, since this dualism may be biasing the search for the link between conditioning activities, physiological mechanisms, and their purported performance improvements. For instance, the deviating time course of performance enhancements (<5 min) and twitch verification (>5 min) after voluntary conditioning activities have also been reported in laboratory conditions.[11] Further, a very recent study found that drop jumps (DJ) performed 2-min before the twitch verification test (i.e., PAP), also enhanced supramaximal cycling performance (i.e., PAPE) and glycolytic energy contribution.[12] However, similar to other investigations, this recent study[12] did not verify the MLC phosphorylation levels with muscle biopsies, suggesting that another physiological mechanism may be involved (i.e., glycolytic energy contribution).

Therefore, the major arguments for the PAP vs. PAPE dualism are not well supported in all cases. These limitations highlight the necessity of a taxonomy of PAP to better identify the potentiation effects of conditioning activities in distinct sport settings, without biasing its potential physiological attributes. Thus, this commentary aims to briefly discuss the current knowledge, and justify and propose a new taxonomy for PAP and its possible applications in sport.

**Limitations of the current evidence: the problem of linking mechanisms and verification tests**

A historical overview of the studies on muscle potentiation reveals an activity-dependent terminology of potentiation studies (see Table 1), which is related to electrically evoked stimuli (i.e., staircase and post-tetanic potentiation) versus voluntary stimuli (i.e., PAP). However, the recent inclusion of the term PAPE does not follow this criterium and is related to the verification procedure, with PAP requiring twitch verification (voluntary activity → twitch verification), while PAPE would be used when the verification occurs with any type of exercise (voluntary activity → voluntary activity). The main reason for this differentiation would be that twitch verification only evaluates peripheral changes, as it is not influenced by potential spinal and supraspinal influences.[13] Blazevich and Babault[10] suggested that other peripheral, non-phosphorylation-dependent processes related to $Ca^{2+}$ sensitivity (i.e., muscle temperature, [pH], and water content) would be more related to PAPE, but there is no reason to disregard that these mechanisms could also influence twitch verification results. In addition, most evidence linking MLC phosphorylation and enhanced force production capacity of fast-twitch fibers has been elaborated from animal models,[7] with humans presenting evidence of similar MLC phosphorylation levels of both fast- and slow-twitch fibers, which could be related to the different evolutionary paths between species.[14] Further, differences in laboratory (*ex vivo, in vivo,* and *in vitro*) and field experiments related to contraction modes (i.e., concentric, isometric, eccentric, stretch-shortening cycle), sarcomere lengths, resting [$Ca^{2+}$], and genetic variants of both kinases and phosphatases among other factors,[7] may also influence the potentiation effects. Furthermore, potentiation phenomena are always accompanied by varying levels of fatigue of different origins,[15,16] complicating the relationship between potentiation mechanisms and verification tests results. Therefore, the interaction of a number of peripheral potentiation mechanisms with fatigue, makes questionable the sole proposed link between MLC phosphorylation and PAP. Meanwhile, the use of PAPE would only be valid to verify the potentiation effect in voluntary exercises, independent of the potentiation mechanisms involved in each specific case. However, there are situations whereby both PAP and PAPE could be influencing performance. For example, Low et al. (2019)[17] used band-resisted squat jumps as the conditioning activity with a 5×1 km interval runs (3 min of recovery) as well as voluntary and evoked contractile properties as the subsequent performance and mechanism measures. While time to complete specific kilometer intervals (e.g., 1st and 4th km) and jump height and reactive strength index improved, the time to peak twitch decreased (higher rate of force development) following the third kilometer interval as well as at 10 minutes post-run. The seemingly PAP-induced improvement in the rate of twitch contraction force could not conceivably be attributed to the original conditioning activity, but PAP influences could have been sustained with the kilometer run intervals. Hence, the performance testing measure may have ensured that both PAP and PAPE mechanisms were contributing concurrently. Thus, strict definitions of PAP and PAPE in these situations would not adequately describe the phenomena.

*** Place Table 1 about here ***

Another relevant confounding factor refers to the key influence of athletes' training background[4] (i.e., strength levels and experience) and sex[18] on potentiation responses, which are not always considered. For instance, speed-power athletes (e.g., sprinters and jumpers) could benefit more from brief, high-intensity conditioning activities, while endurance athletes (e.g., marathon runners and triathletes) would benefit more from submaximal prolonged conditioning activities due to an optimized PAP/fatigue balance.[14] This factor possibly explains the high variability observed between athletes when applying well standardized conditioning protocols.[19]

Within this picture, it is inappropriate to definitively link conditioning activities, physiological mechanisms, and verification tests, since the same conditioning activity may enhance strength capacity via several physiological mechanisms, while potentiation responses would be observable with different verification tests. In addition, the role of athletes' characteristics is another important factor to be highlighted when comparing the potentiation effects of distinct conditioning protocols. Furthermore, there is conflicting evidence regarding the influence of spinal and supraspinal mechanisms on potentiation[20,11,14,21] which may be a problem of sensitivity (i.e., signal-to-noise ratio) that warrants additional research.

## The New Taxonomy

Given all the aforementioned limitations of the current state of the art, we propose that the enhancement of any muscle performance, with simple or complex verification tests, could be better taxonomized using another model, which would consider conditioning stimuli, verification tests, and population of athletes, as main factors involved in these relationships and subsequent classifications:

**Post- [CONDITIONING ACTIVITY] [VERIFICATION TEST] potentiation in [POPULATION]**

Examples:

Post-high intensity squatting jump potentiation in resistance trained males.

Post-submaximal running jump potentiation in female endurance runners.

Post-eccentric flywheel squatting swim start potentiation in varsity trained male swimmers.

Using this model, any conditioning activity would have its own physiological (potentiating and fatiguing) associated mechanism(s), which could be specifically identified in each case with additional experiments. Moreover, the association of a verification test to the potentiation responses, would assist to better recognize the signal-to-noise ratio after identification of the error associated with the test. Further, the application of the conditioning activity to a very homogenous group of athletes, would minimize the variability of potentiation responses, therefore favoring the validity and applicability of the findings. Of note, considering that potentiation mechanisms are mainly muscle memory mechanisms,[7] it should be preferable that athletes be evaluated with well-known exercises or, at least, be fully familiarized before testing. Finally, the terms PAP and PAPE could be independently used when appropriate, with

PAPE being applicable in most cases when a conditioning protocol is followed by a single exercise as verification test. However, as recently observed,[12] the simultaneous existence of PAP and PAPE should not be disregarded. In this manner, this recent study[12] would be seen as: "Post-drop jumps supramaximal cycling potentiation in recreational male cyclists (via PAP and augmented glycolytic energy contribution). Similarly, another recent study[3] found that a variety of conditioning protocols resulted in enhanced change of direction performances (i.e., PAPE) with observable changes in tensiomyography parameters (i.e., PAP).

**Practical Applications: The Need for Individualized Approaches**

A thorough examination of the contemporary potentiation (PAP and PAPE) scientific literature highlights two main evidence-based recommendations for practitioners. Firstly, potentiation strategies can be broadly used to acutely enhance athletic performances of both individual and team sport athletes.[6,18,22] Secondly, the high inter-individual variability and inconsistency of the potentiation responses indicate the need for individualized approaches.[23,24] Thus, conditioning protocols looking for potentiation responses can be implemented in the following settings:

- Testing: incorporated into standardized warm-up routines of assessment procedures intended to assess maximal athletic performance at different moments of the season. This may help limiting confounding effects arising from different warm-up protocols, thus facilitating a more consistent interpretation of the performance results.[12,18,25]
- Training: as part of advanced programs in which the conditioning activity is paired with an unloaded explosive exercise (e.g., loaded squats + vertical jumps), and performed immediately after or following a brief rest interval (i.e. complex training or contrast training).[26]

- Competition: incorporated into warm-up strategies completed at a precise timing prior to official competitions.[27]

Although performance potentiation mean effects are commonly observed at a group level in well standardized conditions, inconsistent findings are reported between individuals even performing the same potentiating protocols.[18,19,24] Therefore, practitioners should be aware that the individual characteristics of athletes may lead to different responses in terms of onset and magnitude of potentiation effects. Recurring evidence suggest a more individualized approach to optimize potentiation effects by manipulating the conditioning protocol variables with the identification of intensity, volume, and recovery time, for determining optimal loads adapted to the training background and sex of athletes.[4,18,24,28] However, contrary to frequent claims, there is no evidence supporting the need of performing biomechanically similar exercises during conditioning protocols to benefit from potentiation responses.[3]

For meeting these objectives, the new taxonomy would be very helpful as it avoids the inadequate use of protocols in sport settings and populations different to those in which they exhibited effectiveness. Nonetheless, after identifying customized conditioning protocols from the scientific literature, practitioners would also need to test their efficacy in specific settings, after manipulating the conditioning protocol variables, on an individual basis. Meanwhile, sport physiologists would be able to better and more precisely identify the mechanisms associated with potentiation responses for augmenting the translational value of laboratory results to the field, following previous methodological recommendations.[10] In this regard, reporting negative results would also be important to improve this process, given the existing bias of publishing more positive outcomes. Finally, sport scientists are suggested to examine and report the individual responses of well-characterized athletes (e.g., sex, training experience, competitive level, period of the season) in order to better identify the factors associated with both responder and non-responder groups.

## Conclusions

We presented a novel taxonomy for the classification of potentiation in sport. This taxonomy encompasses the identification of the conditioning activity, verification test, and athletic population according to this formula: Post- [CONDITIONING ACTIVITY] [VERIFICATION TEST] potentiation in [POPULATION]. This proposal may potentially avoid erroneous identification of physiological attributes, which should be studied separately, while favoring individualization and applicability of conditioning protocols in sport settings. The use of PAP and PAPE would be valid, but assuming that both definitions could be complementary in some cases.

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Table 1. Link between terminology and activity in potentiation studies.[10]

| Term | Definition |
|---|---|
| Staircase potentiation | A progressive increase in twitch contractile response during repeated low-frequency stimulations. |
| Post-tetanic potentiation (PTP) | An increase in amplitude of twitch tension after a sustained muscle tetanic stimulation, generally at a high stimulation frequency. |
| Post-activation potentiation (PAP) | Augmentation of evoked twitch tension induced by voluntary activation of the muscle. |
| Post-activation performance enhancement (PAPE) | Enhancement of subsequent voluntary, rather than electrically evoked (twitch), force production, following high-intensity voluntary conditioning contraction(s). |