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ORIGINAL RESEARCH

# The post-activation performance enhancement effect of a parallel back squat on male jumping and sprinting athletes

Enrique Márquez[1], Daniel Castillo[1,*], Alejandro Rodríguez-Fernández[2], Marco Beato[3], Javier Raya-González[4]

[1]REDAFLED Research Group, University of Valladolid, 42004 Soria, Spain
[2]VALFIS Research Group, Institute of Biomedicine (IBIOMED), University of Leon, 24004 Leon, Spain
[3]School of Health and Sports Science, University of Suffolk, IP4 1QJ Ipswich, UK
[4]Faculty of Health Sciences, University of Extremadura, 10003 Cáceres, Spain

***Correspondence**
danicasti5@gmail.com
(Daniel Castillo)

## Abstract

Although the literature has described different ways and methodologies of producing chronic neuromuscular enhancements in athletes, less is known about warm-up activities aiming to optimize short-term performance. To address these gaps, investigations into post-activation performance enhancement (PAPE) effects are necessary. As such, this work aimed to analyse the PAPE effect of different parallel squat (PS) protocols with and without whole-body vibration (WBV) employing different volumes (low and high) and rest periods (of one and four minutes) on jumping performance. Seventeen elite sprinting and jumping male athletes participated in this study. The athletes completed one PAPE protocol on a weekly basis, according to the following conditions: PS with 80% one-repetition maximum (1RM) without vibration (NV-PS) and with WBV (WBV-PS). Each exercise was performed at a high and low volume, and after short or long recovery periods (of one and four minutes). A countermovement jump (CMJ) and drop jump (DJ) without an arm swing were executed before and after each PAPE protocol. Higher CMJ and DJ performances after WBV-PS exercises were found (effect size (ES) = 1.065–1.319, large). Greater DJ results were observed after an NV-PS exercise with a high volume and four minutes of rest (37.78 ± 5.44 *vs.* 39.09 ± 5.62; $p = 0.011$; ES = 0.692, medium). Time x condition effects (F = 25.239, $p < 0.01$, $\eta^2 = 0.03$) were observed, revealing higher CMJ values after a WBV-PS in comparison to baseline conditions, as well as higher DJ values after NV-PS and WBV-PS in comparison to baseline conditions. The findings indicate that these types of PAPE protocols in elite male athletes and WBV-PS PAPE protocols in particular can enhance CMJ and DJ performance, while the NV-PS (using a high volume and four minutes of rest) resulted in improvements for the DJ. No other improvements were reported using NV-PS combinations.

## Keywords

Athletics; Nuromuscular; Activation; Whole-body vibration

## 1. Introduction

Sport science practitioners aim to increase athletes' performance through different physical and physiological strategies (*e.g.*, supplementation or hydration) [1]. Although the literature has described different methodologies for producing chronic neuromuscular enhancements in athletes [2], less is known about warm-up activities aiming to optimize short-term performance, which have gained attention in recent years [3]. These acute strategies are based on the post-activation performance enhancement (PAPE) principle, a physiological phenomenon that enhances the muscle contractile response for a given level of stimulation following an intense voluntary contraction [4, 5]. PAPE occurs due to the phosphorylation of myosin light chains resulting from the initial muscle activity, which makes the actin and myosin molecules more sensitive to calcium availability [6]. In addition, one investigation has claimed that the effects of PAPE are related to increases in the recruitment of higher-order motor units, changes in the pennation angle, and rises in muscular stiffness [6]. Other authors have proposed different explanations, but the physiological mechanism is still not fully understood [3]. Although the procedure of this mechanism is not clear, PAPE studies have reported improvements in muscle force and power following specific warm-up protocols, leading to significant boosts in the performance of sport-specific actions/movements, such as sprinting and jumping [3, 7].

Resistance training is considered a valid method of favouring the PAPE effects in athletes, and traditional exercises (*e.g.*, squat variations) are the type most used by coaches to elicit a greater PAPE response for subsequent sport actions [8]. Specifically, Beato *et al.* [9] compared two PAPE protocols, including an eccentric overload squat and traditional weightlifting squat exercises, on jumping performance in male athletes and found significant increases in relation to the countermovement jump (CMJ) and standing long jump. Moreover, the authors observed significant improvements after three and seven minutes following the PAPE protocol, while no major differences were noted after one minute of recovery, which suggests that a recovery time is needed to obtain a potentiation following the PAPE protocol. Instead, Timon *et al.* [10] employed a PAPE protocol based on the half-squat exercise (three sets of six repetitions at the maximum power load, with a three-minute rest interval between sets) with physically active participants, and they observed non-significant variations in the squat jump (SJ) height four minutes after the PAPE protocol. This means that PAPE time window could be associated with the potentiation protocol utilized [7]. On the other hand, Petisco *et al.* [11] employed a PAPE protocol based on a single set of half-back squats and compared the effect of different loads (*i.e.*, 10 repetitions at 60% of one-repetition maximum (1RM), five repetitions at 80% of 1RM, and one repetition at 100% of 1RM) with professional soccer players. These authors observed significant improvements in the CMJ after six minutes and in the SJ after eight minutes following the 60% 1RM protocol only. These discrepancies in the current literature may be the result of differences in the interventions relating to protocol characteristics including the exercise modality, volume, intensity, and duration of rest between the preceding exercise and the subsequent sportive one [7, 12]. Therefore, all these key variables should be modulated to obtain a perfect balance between acute fatigue and the PAPE response [13].

Recently, some researchers have attempted to increase the acute performance responses of their athletes and have chosen to incorporate non-traditional training modalities such as whole-body vibration (WBV) [14, 15]. The vibratory exercise uses a platform that oscillates at a predetermined amplitude and frequency, sending the desired vibrations to the body of the athlete who is standing on the platform [16]. WBV is based on an excitatory response of the muscle spindles, due to the stretch reflex mechanism, which increases motor unit recruitment in the implicated muscles [15]. In addition, vibration has been shown to stimulate transient increases in certain hormones, such as growth hormone and insulin-like growth factor I (IGF-I) [17]. These mechanisms suggest that the use of vibration is a viable strategy for improving performance in competition. Specifically, Bedient *et al.* [18] observed an increase in jumping ability one minute after the stimulating WBV exercise, which involved maintaining an isometric half-squat position for 30 seconds at frequencies of 30–40 Hz and 2 to 8 mm amplitude. However, Cochrane *et al.* [19] observed no acute effects of WBV on jump, sprint, or agility performance. Combining WBV with resistance training may offer a way of solving this problem, as it may induce a more pronounced neuromuscular acute response compared to isolated methods. In this regard, Naclerio *et al.* [20] observed improvements in the CMJ with American football and baseball athletes four minutes after the application of a PAPE protocol based on WBV combined with the parallel squat (PS) exercise (one set of three repetitions or three sets of three repetitions with two minutes of rest between sets), although this enhancement was not observed one minute after the PAPE protocol.

Despite these promising results, investigations into the effect of combined resistance and vibration exercises are scarce. To address the gaps identified in the literature regarding PAPE protocols, the aim of this study was to analyse the PAPE effect of different PS protocols with and without WBV using different exercise volumes (high and low) and rest periods (of one minute and four minutes) on jumping performance in elite athletes. It is hypothesized that PS combined with WBV is more effective than PS in isolation and this would be independent of the volume of the protocol. Additionally, a long (four minutes) instead of a short recovery time (one minute) would be needed for enhancing jumping performance.

## 2. Materials and Methods

### 2.1 Participants

Seventeen elite sprinting and jumping male athletes (age: 21.1 ± 4.8 years, height: 181.1 ± 5.6 cm, weight 73.0 ± 8.3 kg), in running and jumping athletic disciplines, who belonged to a high-performance athletics centre volunteered to participate in this investigation. To investigate PAPE in these populations could enhance athletic performance. All participants performed at least five training sessions per week during a three-year period and were healthy and free of any musculoskeletal injury. Prior to testing, the participants were informed of the research procedures, protocols, benefits, and risks and provided written informed consent. All procedures were approved by institutional Research Ethics Committee (***omitted for blind review***) and this study was performed in accordance with the Declaration of Helsinki.

### 2.2 Measures

Jumping variables. After an initial week of familiarization consisting of CMJs and drop jumps (DJs) performed from different heights with the aim of improving jumping and landing techniques, the participants completed two testing sessions with a gap of between 24 and 48 h. The first session consisted of determining the optimal DJ height using this protocol, starting at a height of 10 cm with 10 cm increments at each attempt. The participants were instructed to keep their hands on their hips, maximize the jump height and minimize the ground contact time during the jump [21]. Take-off and landing were standardized to full knee and ankle extension on the same spot. Three repetitions were performed from each drop height with a five-second rest between the trials [20] until the optimal height was obtained without exceeding 250 ms. The second session consisted of determining the 1RM PS through a series of two repetitions with increasing weights and pauses of two to four minutes, as in a previous study [22].

PAPE protocols. In the following eight weeks, the participants performed two different main actions, including PS with 80% 1RM without vibration (NV-PS), and PS with 80% 1RM on a WBV platform (WBV-PS). Each exercise was performed at low (*i.e.*, one set of three repetitions) and high (*i.e.*, three sets of three repetitions) volumes with two minutes of rest between sets and after a short (one-minute) or long (four-minute) recovery time, similar to previous studies with male college athletes (eight American football and seven baseball

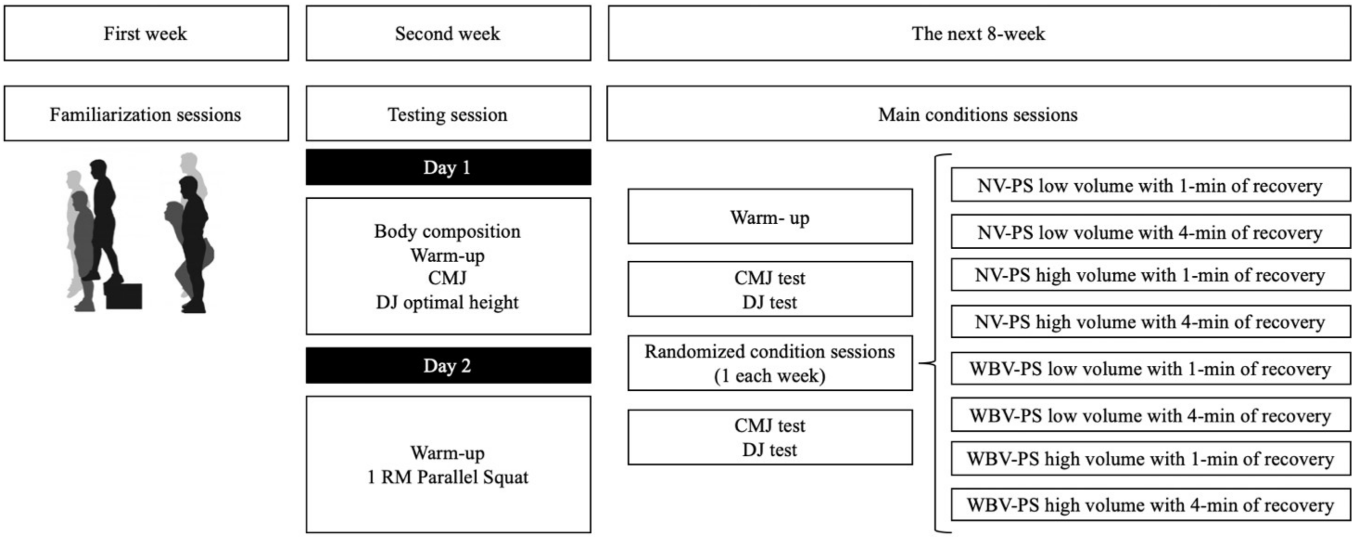


**FIGURE 1. Schematic representation of the study design.** 1RM, one maximal repetition; PS, parallel squat; CMJ, countermovement jump; DJ, drop jump; NV-PS, parallel squat without vibration; WBV-PS, parallel squat onto a whole-body vibration platform.

players) [20]. As a baseline and following the PAPE protocols, the athletes performed three CMJ attempts keeping their hands on their hips with 45 seconds of recovery. The athletes were instructed to perform a downward movement at a self-selected, comfortable depth followed by a rapid extension of the lower-limb joints during each jump. The athletes also performed three DJ attempts at the optimal individual height before and after the PAPE protocols. In both jumps, the highest score was selected for further analysis. A photocell system (Optojump, Microgate™, Bolzano, Italy) was used to measure the jump height (cm), which presented very high intraclass correlation coefficients regarding validity (0.997–0.998), excellent test-retest reliability (0.982–0.989), and low coefficients in terms of variation (2.7%).

During the experimental conditions, the participants performed a PS with the maximum possible velocity during the concentric phase and controlled the decent phase. The frequency used by the Power Plate platform (Power Plate North America, Inc., Northbrook, IL, USA) was set to 40 Hz and 1.963 mm peak to-peak amplitude [23]. Before the baseline test, two testing sessions and eight condition sessions, the participants performed the same standardized warm-up (flexibility and joint mobility exercises, and one set of three to five repetitions with light weights in PS, followed by two minutes of rest). All the actions were performed with a randomized counterbalance on the same day of the week with 48 h of recovery after the previous training session—see Fig. 1.

## 2.3 Statistical Analysis

Descriptive statistics (mean ± standard deviation (SD)) were used to determine the participant and dependent variable characteristics. The Kolmogorov-Smirnov test was applied to verify the normal distribution of the data and the Levene test to assess the homogeneity of variance. A repeated-measures four-way (two conditions × two volumes × two rests × two testing times) analysis of variance (ANOVA) and the Bonferroni post hoc test were performed to evaluate the potentiation effect on the jumping variables (*i.e.*, CMJ and DJ). Eta-squared ($\eta^2$) values were calculated to estimate the effect size (ES), which was considered either small ($\eta^2 = 0.01$), medium ($\eta^2 = 0.06$), or large ($\eta^2 = 0.14$) [24]. Paired samples *t*-tests were utilized to determine the individual training effect from the baseline to after the protocols. Cohen's d was also employed as a measure of standardized ES, using the small (d = 0.2), medium (d = 0.5), and large (d = 0.8) reference values [25]. The level of significance was set at $p < 0.05$. Statistical analyses were performed with JASP (Amsterdam, Netherland) software version 0.13.1.

## 3. Results

Higher CMJ values were found after the WBV-PS exercise with a low volume and one minute of rest, and with low and high volumes and one- and four-minute rests ($p < 0.05$; ES = 1.065–1.319, large) compared to the baseline (Table 1, Figs. 2,3). Moreover, higher DJ values were reported after the WBV-PS exercise with any volume and rest condition ($p < 0.05$; ES = 0.802–2.128, large) and after the NV-PS exercise with a high volume and a four-minute rest ($p = 0.002$; ES = 0.692, medium), in comparison to the baseline (Table 1, Figs. 4,5).

No significant major effects from the condition (NV-PS or WBV-PS) × volume (low or high) × rest period (of one or four minutes) × testing time (baseline or post) were observed for the CMJ or DJ heights ($p > 0.05$). Regardless of the CMJ potentiation effects, major effects for time × condition (F = 25.239, $p < 0.01$, $\eta^2 = 0.03$) were found. Post hoc analyses revealed higher CMJ values after the WBV-PS form ($p < 0.001$) in respect to the baseline. Regarding the DJ potentiation effects, major effects for time × condition (F = 13.417, $p < 0.01$, $\eta^2 = 0.03$) were observed. Post hoc analyses revealed higher DJ values after the NV-PS ($p = 0.011$) and WBV-PS ($p < 0.001$) types in comparison to the baseline.

**TABLE 1. Results (mean ± SD) of jumping performances at baseline and after each post-activation potentiation protocol.**

| Jump | Condition | Volume | Recovery | Baseline | Post | *p* | ES |
|---|---|---|---|---|---|---|---|
| CMJ | NV-PS | Low | 1 min | 42.05 ± 5.92 | 42.28 ± 6.09 | 0.492 | 0.171 |
| | | | 4 min | 42.03 ± 6.80 | 41.84 ± 6.99 | 0.550 | –0.148 |
| | | High | 1 min | 42.95 ± 6.86 | 43.79 ± 6.78 | 0.062 | 0.487 |
| | | | 4 min | 42.38 ± 6.89 | 42.78 ± 6.55 | 0.325 | 0.246 |
| | WBV-PS | Low | 1 min | 41.47 ± 6.29 | 43.56 ± 6.87 | <0.001 | 1.125 |
| | | | 4 min | 41.68 ± 6.09 | 42.48 ± 6.58 | 0.094 | 0.432 |
| | | High | 1 min | 41.45 ± 5.79 | 43.49 ± 6.45 | <0.001 | 1.319 |
| | | | 4 min | 41.65 ± 6.81 | 43.75 ± 6.70 | <0.001 | 1.065 |
| DJ | NV-PS | Low | 1 min | 37.18 ± 5.72 | 38.04 ± 5.69 | 0.057 | 0.499 |
| | | | 4 min | 37.13 ± 6.15 | 37.29 ± 6.35 | 0.788 | 0.066 |
| | | High | 1 min | 38.74 ± 5.88 | 39.47 ± 5.68 | 0.196 | 0.327 |
| | | | 4 min | 37.78 ± 5.44 | 39.09 ± 5.62 | 0.011 | 0.692 |
| | WBV-PS | Low | 1 min | 37.13 ± 4.62 | 38.51 ± 5.58 | 0.002 | 0.890 |
| | | | 4 min | 36.97 ± 5.30 | 38.87 ± 5.19 | <0.001 | 2.128 |
| | | High | 1 min | 36.40 ± 4.97 | 39.08 ± 5.24 | <0.001 | 1.294 |
| | | | 4 min | 36.88 ± 5.19 | 38.93 ± 5.16 | 0.004 | 0.802 |

*Note. NV-PS, parallel squat without vibration; WBV-PS, parallel squat onto whole body vibration platform; CMJ, countermovement jump; DJ, drop jump; p, level of significance; ES, effect size.*

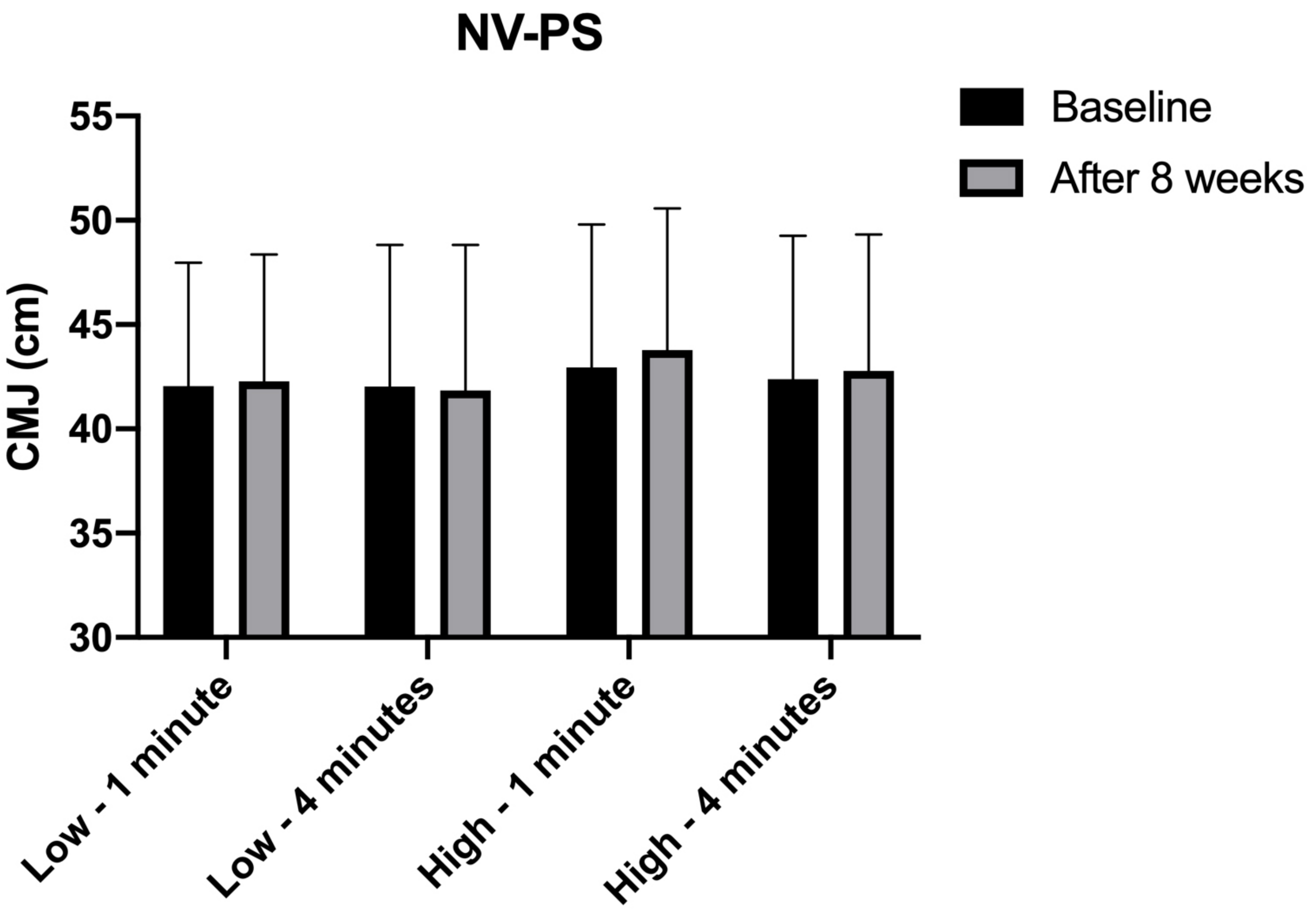


**FIGURE 2. Differences between baseline and after post-activation potentiation protocols in terms of volume and rest duration for countermovement jump (CMJ) in parallel squat without vibration (NV-PS).**

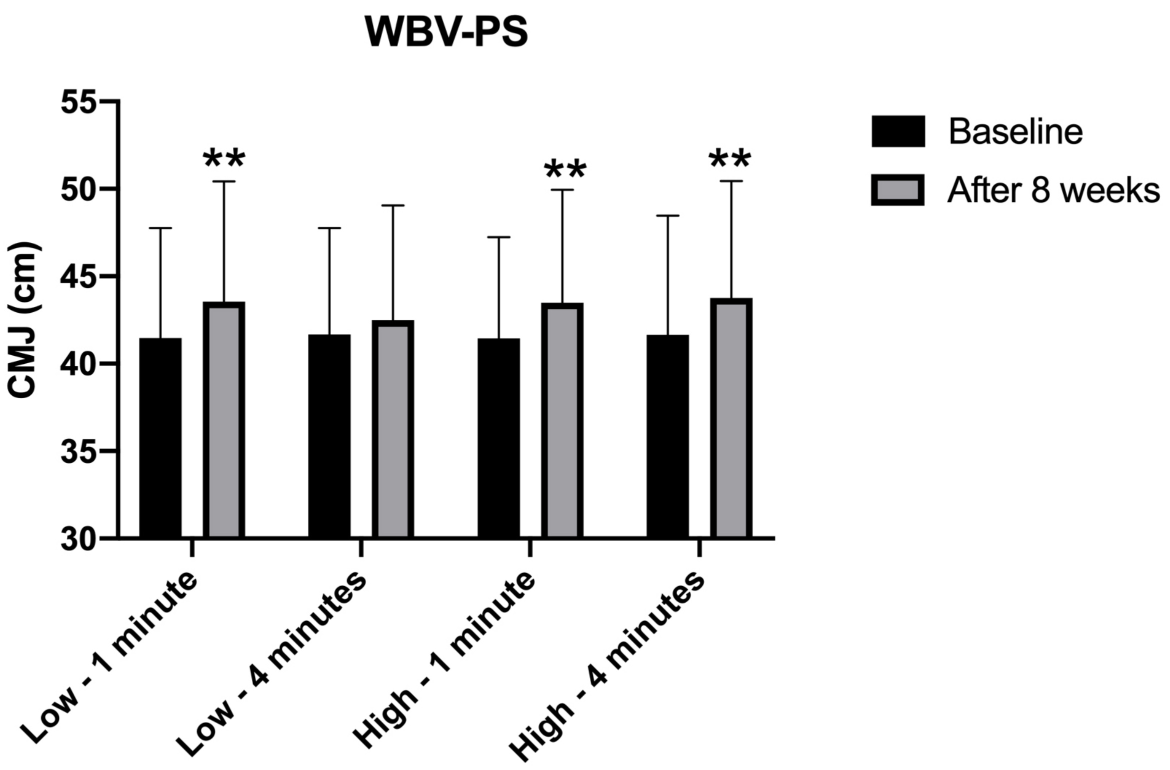


**FIGURE 3. Differences between baseline and after post-activation potentiation protocols in terms of volume and rest duration for countermovement jump (CMJ) in parallel squat onto a whole-body vibration platform (WBV-PS).** **Significant differences ($p < 0.001$) when comparing post-protocol results with baseline.

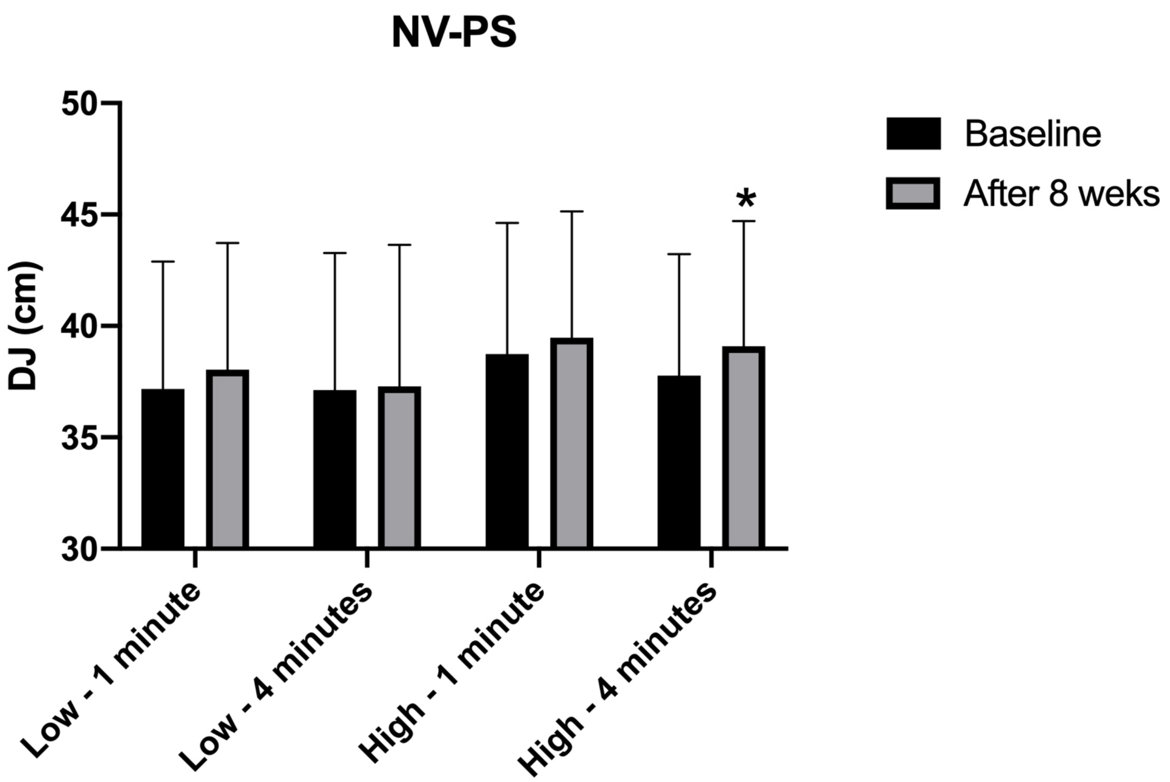


**FIGURE 4. Differences between baseline and after post-activation potentiation protocols in terms of volume and rest duration for drop jump (DJ) in parallel squat without vibration (NV-PS).** *Significant differences ($p < 0.05$) when comparing post-protocol results with baseline.

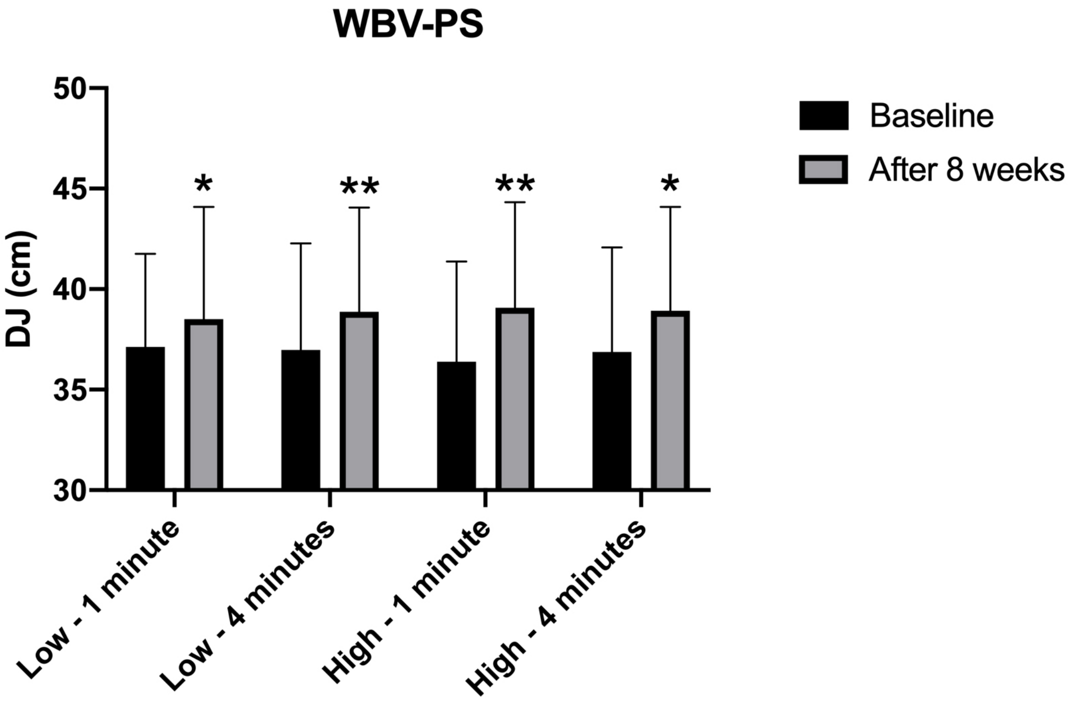


**FIGURE 5. Differences between baseline and after post-activation potentiation protocols attending to volume and rest for drop jump (DJ) in parallel squat onto a whole-body vibration platform (WBV-PS).** *Significant differences ($p < 0.05$) when comparing post-protocol results with baseline; **Significant differences ($p < 0.001$) when comparing post-protocol results with baseline.

## 4. Discussion

The aim of this study was to analyse the PAPE effect of different PS protocols with and without WBV using different exercise volumes (low and high) and rest periods (of one minute and four minutes) on jumping performance in male elite athletes. This work is the first to investigate these types of PAPE protocols in male elite athletes and found that WBV-PS PAPE protocols can enhance CMJ and DJ performance, while the NV-PS type (using a high volume and four minutes of recovery) resulted in improvements for the DJ. However, no other improvements were reported utilizing NV-PS combinations. Moreover, this investigation shows that improvements can be associated with different time windows (one minute or four minutes of recovery) as well as employing a low or high WBV-PS volume. These findings should be considered by practitioners in sports sciences who aim to optimize a pre-activation stage consisting of a combination of resistance and vibration protocols to increase CMJ and DJ performance in male elite athletes.

Vertical jumps are valid "ecological" measures of acute muscle potentiation, which are capable of detecting changes in highly trained athletes in response to the PAPE phenomenon [26], while the squat exercise (using different loads) is one of the main methods for eliciting PAPE effects [8]. However, no conclusive results have been identified in regard to the most suitable volume, intensity, and rest periods for obtaining PAPE effects. The results reported in this research showed greater CMJ and DJ values following the WBV-PS exercise using one set of three repetitions with 80% 1RM (one minute of rest), and one set of three repetitions and three sets of two repetitions of 80% 1RM (with one and four minutes of rest), which highlights the validity of WBV-PS in stimulating some PAPE responses. Our results are supported by Naclerio *et al*. [20] who observed improvements in CMJ performance four minutes after the application of similar PAPE protocols involving American footballers. However, our analysis also found PAPE improvements after one minute. These differences could be explained by the participants' level and the type of sport practised by these athletes. For instance, our investigation involved a sample of male elite athletes who seem to need a lower rest time to enhance their jump performance. To our knowledge, no other study has implemented similar WBV strategies, although other investigations have shown the effectiveness of adding WBV prior to resistance training exercises to improve explosive strength [16, 18]. Considering the aforementioned findings, it seems appropriate to apply a WBV strategy to optimize the male athletes' jumping performance, which is a novel conclusion reported by this research.

Our results also showed a higher DJ performance after the NV-PS protocol with three sets of two repetitions of 80% RM, allowing for four minutes of rest. Previous works found improvements in CMJ after the application of squat protocols using varying volumes (*e.g.*, three sets of six repetitions with two minutes of rest, three sets of six repetitions with three minutes of rest, one set of 10 repetitions at 60% RM, one set of three repetitions at 100% RM) and performing the CMJ after at least three minutes of recovery [9, 11, 27]. However, no consensus has been reached related to the acute effects on specific sport performance in terms of exercise modality, volume, intensity, and duration of rest. In addition, no studies analysing the PAPE effects on DJ performance have previously been performed. Therefore, the results of this investigation are new and cannot be directly compared with previous research: this analysis showed greater performances after the application of the aforementioned PAPE protocol in terms of the DJ but not the CMJ, which could be due to the role played by the musculature and tendon unit during the shortening-stretching cycle during the DJ. This could explain the differences in the results when compared to the CMJ performance [28]. As such, since the squat is one of the most commonly implemented exercises with athletes [29, 30], it would be advisable for strength and conditioning specialists to prescribe the NV-PS exercise at a high volume and allow for four minutes of rest following the PAPE protocol prior to performing the planned sport-specific task (*e.g.*, jumping activities).

It appears that the optimal time window to achieve PAPE effects in sport-specific tasks should be between four to eight minutes [31], although no clear data have been published. The results obtained in our study were reported in an individualized manner showing the effect of each PAPE protocol. However, it would be interesting to analyse whether the improvements in vertical jump performances are significantly different in comparison to other PAPE protocols. In this sense, a significant interaction was observed for time $\times$ condition, revealing that CMJ height was higher after the WBV-PS exercise, and that DJ height was higher after WBV-PS and NV-PS exercises. These findings suggest that adding the WBV strategy to resistance exercises may elicit a PAPE response, leading to acute improvements in the CMJ and DJ. In addition, the NV-PS exercise could be regarded as highly enhancing performance in terms of DJ height.

This study is not without limitations. First, this research involved a small sample of male elite athletes, so the results cannot be generalized in terms of other samples with different characteristics, such as amateur athletes or those from different sport disciplines who may exhibit different PAPE time window and magnitude responses [9, 13]. Second, although the stimulus planned for the eight weeks of training was similar, it would have been interesting to quantify the physiological responses or perceived exertion by the athletes with the aim of understanding whether all the training weeks and protocols generated the same response. Third, since PAPE responses could be affected by the sex of the athletes because of the related physiological characteristics, further research could investigate whether the acute effects on neuromuscular performance after the PAPE protocols used in this investigation would produce similar results in female populations. Fourth, since only the jump height has been assessed, additional works could evaluate a kinematic analysis of jump tests. Finally, considering that not all athletes are responsive to PAPE protocols due to their physical and physiological characteristics (*e.g.*, fitness level) [32], it could be interesting, in additional analyses, to differentiate the responders and non-responders following PAPE protocols.

## 5. Conclusions

This study shows that WBV-PS PAPE protocols can enhance CMJ and DJ performance. The NV-PS form demonstrated improvements for only the DJ using a high volume and allowing for four minutes of recovery, but no other improvements were reported from employing NV-PS protocols. Therefore, adding WBV during resistance training PAPE protocols could be a valid strategy for improving the subsequent jumping performance before competitions and training sessions, while NV-PS PAPE protocols could improve DJ performance. Moreover, this paper reveals that improvements can be found by utilizing a low or high volume of WBV-PS exercises and allowing one minute or four minutes of recovery after the PAPE exercise. These findings should be considered by practitioners in sports sciences who aim to optimize a pre-activation phase consisting of a combination of resistance and vibration protocols to increase CMJ and DJ performance in male elite athletes.

### AVAILABILITY OF DATA AND MATERIALS

The data that support the findings of this study are available from Centro de Alto Rendimiento y Promoción Deportiva (CAEP) of Soria but restrictions apply to the availability of these data, which were used under license for the current study, and so are not publicly available. Data are however available from the authors upon reasonable request and with permission of CAEP Soria.

### AUTHOR CONTRIBUTIONS

EM and DC—designed the research study. EM—performed the research. MB—provided help and advice on reviewing the manuscript. DC—analyzed the data. DC, ARF and JRG—wrote the manuscript. All authors contributed to editorial changes in the manuscript. All authors read and approved the final manuscript.

### ETHICS APPROVAL AND CONSENT TO PARTICIPATE

Prior to testing, participants were informed of research procedures, protocols, benefits, and risks and provided written informed consent. All procedures were approved by local institutional Research Ethics Committee of Hospital Clínico Universitario de Valladolid (Code = PI 21-2478).

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## CONFLICT OF INTEREST

The authors declare no conflict of interest.

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