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Whole body vibration and drop jumps induce post-activation performance enhancement

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ABSTRACT
Purpose. Many studies have investigated the effect of whole body vibration (WBV) exercise on post-activation potentiation. It was reported that an intervention protocol of WBV combined with 5 drop jumps (DJs) led to an increase in twitch force, suggesting the occurrence of post-activation potentiation. The purpose of this study was to examine the acute effect of different warm-up interventions on countermovement jump (CMJ) performance by recording jump height, power, and take-off velocity in gymnasts.
Methods. Overall, 10 adult gymnasts (mean age: 22.80 ± 1.75 years; body mass: 61.92 ± 8.65 kg; body height: 170.10 ± 8.65 cm) with 16.35 ± 5.68 years of training experience volunteered to participate in this study. The interventions were (i) WBV, (ii) no vibration, (iii) DJs, and (iv) WBV combined with DJs (WBVDJ). Over 4 distinct randomized testing sessions, the gymnasts performed pre-intervention tests comprising 3 CMJs, followed by one of the 4 interventions; after 8 min, they performed another set of 3 CMJs.
Results. A significant interaction was observed between interventions for jump height and take-off velocity, leading to improvements (+4.82%, $p < 0.05$; +2.50%, $p < 0.05$, respectively) after WBVDJ only. No significant improvements were noted for WBV, DJs, or no vibration interventions. The implementation of WBVDJ was an effective stimulus leading to post-activation performance enhancement of CMJ in gymnasts.
Conclusions. The WBVDJ intervention increased jump height of CMJ performance and take-off velocity of lower limbs. In addition, WBVDJ led to greater performance improvement compared with DJ intervention.
Key words: gymnasts, plyometric exercise, vibration, post-activation potentiation

Introduction

In gymnastics, to successfully perform a series of acrobatics elements or a vaulting jump, athletes require sufficient explosive power of the lower limbs [1, 2]. Consequently, gymnasts often use plyometric exercises, such as drop jumps (DJs) and countermovement jumps (CMJs), as a conditioning stimulus in order to acutely improve sport-specific explosive power and jump performance [3]. For example, plyometric exercises can enhance athletes' sport-specific performance owing to similarities in their technical structure with sport-specific skills [4].

In addition, studies that examined the acute effects of plyometric exercises such as CMJs or DJs reported improvements in jump height and/or maximal power output during subsequent jump performance [5–8]. This acute improvement of performance is based on the post-activation potentiation (PAP) phenomenon, intended to increase muscle twitch force [9], and the term 'post-activation performance enhancement' (PAPE) was recently proposed for settings in which performance rather than twitch force is considered as the main outcome [10]. In this context, a recent study reported that a warm-up routine incorporating DJs induced PAP through improvement of peak twitch torque [11].

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Moreover, a systematic review with meta-analysis highlighted that plyometric exercise produced greater PAPE effects than moderate-intensity traditional resistance exercise [12]. Taken as a whole, these observations suggest that incorporating plyometric exercises in a warm-up or as a pre-conditioning exercise is of importance for subsequent jump performance improvements.

In physical preparation, athletes, coaches, as well as sports scientists are always interested in innovative conditioning exercises that would improve sport-specific performance. Hence, whole body vibration (WBV) has recently gained popularity since it was reported that a bout of WBV exercise led to an increase in twitch force [13, 14], which suggests the occurrence of the PAP phenomenon [13]. Many studies have therefore investigated the promising effect of WBV exercise in PAPE [15, 16]. Although different types of platforms are available, studies conducted on vertical synchronous platforms have shown that PAPE, assessed through jump performance, was evidenced after an acute bout of WBV exercise [17, 18].

More specifically, a study performed in young artistic gymnasts has indicated that dynamic squats practised on a vibrating platform enhanced squat jump performance through PAPE up to 15 min after the intervention [19]. However, the same exercise did not improve CMJ performance. In addition, Dallas and Kirialanis [20] failed to observe significant improvements in squat jump and CMJ performance in adult artistic gymnasts after WBV exercise. Although the heterogeneity of the experimental protocols implemented could account for these inconsistent findings, a recent review also pointed out that designing an effective potentiation intervention was challenging and must consider numerous factors [8]. Amongst these factors, it has been proposed that a complex training stimulus (i.e., performing a heavy resistance exercise prior to executing an explosive movement) could be an effective intervention for enhancing explosive performance [7, 21].

So far, only Chen et al. [22] have attempted to investigate the acute effect of complex training stimuli on PAPE in male college volleyball and basketball players. In their study, the complex interventions comprised resistance exercise or WBV exercise followed by DJs and were compared with resistance, plyometric, and WBV exercise performed in isolation. Although a significant improvement in vertical DJ height was found for all interventions, no difference was observed between interventions. Consequently, the benefit of complex interventions on PAPE remains unsettled.

The purpose of this study was to examine the acute effect of a complex intervention combining WBV and DJs on PAPE assessed by CMJ performance in gymnasts. It was hypothesized that the complex intervention (i.e., WBV and DJ) would induce greater PAPE compared with the WBV or DJ interventions.

Material and methods

Participants

A total of 10 adult gymnasts (mean age: 22.80 ± 1.75 years; body mass: 61.92 ± 8.65 kg; body height: 170.10 ± 8.65 cm; 6 women and 4 men) who participated in national and international competitions, with 16.35 ± 5.68 years of training experience, volunteered to participate in this study. All gymnasts had been free of any injury for at least 6 months prior to testing. All participants were informed of the purpose, the experimental procedures, as well as the possible risks of the study. To verify the sample size of this study, a statistical power calculation was performed [23]. The sample size was adequate for the variables with significant interactions or main effects ($\alpha \leq 0.05$ for type I error), whereas it was not adequate for the variables with no significant interactions or main effects ($\beta \leq 0.2$ for type II error).

Experimental procedures

This study was designed to examine the acute effects of WBV and DJ protocols on CMJ and the related parameters. After completion of a familiarization session (dedicated to accustoming the participants with the intervention protocols and testing procedures), the individuals were tested 4 times in a randomly ordered crossover design (i.e., WBV, sham, DJ, and WBV combined with DJs [WBVDJ] interventions, see below) on 4 separate days (with a 72-hour interval). In each testing session, the subjects first performed a 3-min warm-up run on a treadmill (Technogym Runrace 1200, Gambettola, Italy) at 2.22 $m \cdot s^{-1}$ before performing pre-intervention measurements, followed by the respective experimental intervention and then by post-intervention measurements, completed 8 min after the intervention [24–28]. The pre- and post-intervention testing included 3 CMJs accomplished on a contact mat (Chronojump, Barcelona, Spain), interspersed with a 30-s rest interval. The biggest jump height value of CMJ performance was considered for further analysis. Take-off velocity and power developed during CMJ were obtained from the highest CMJ trial and considered for the analysis. All testing procedures were performed during pre-competition period (October), at the same time of the day (between 4 and 6 o'clock p.m.), in the training sports laboratory of the School of Physical Education and Sport Science of National and Kapodistrian University of Athens. During the testing period, the participants were asked to terminate any other sports activity. Additionally, the gymnasts were instructed to refrain from any other physical activity, food intake, and additional supplementation for 2 hours before exercise and not to consume coffee in the same period.

Interventions

The WBV protocol was performed on a vertical synchronous vibration platform with a 20-mm closed-cell expanded rubber mat (Power Plate®, Northbrook, USA). The vibration frequency and peak-to-peak displacement were respectively set at 50 Hz and 4 mm, which led to a vertical theoretical platform acceleration of 197 $m \cdot s^{-2}$. The WBV protocol included 5 sets of 30-s dynamic squatting exercises on the vibration platform at a tempo of 1.5 s down and 1.5 s up at an approximate depth of 90° knee flexion; each set was immediately followed by a 30-s rest period (duration: 5 min; duty cycle: 50%; total duration of vibration exposure: 2 min 30 s) [24]. During the sham intervention, the participants followed the same protocol but the platform did not vibrate.

The DJ intervention consisted of 5 DJs (1 DJ every 30 s) [24] from a 50-cm box with floor landing with both feet and then immediately jumping as high as possible with hands placed on the hips throughout the trials. Owing to the possible initial upward propulsion, the participants were instructed, while stepping off the box, to use their leading leg, keep their hands on their hips and their knees and ankles fully extended. During landing, the subjects were requested to keep the ground contact time to a minimum and jump as high as possible.

In the complex intervention (WBVDJ), each individual performed 1 DJ immediately after the end of the 30-s WBV exercise with the same procedures as described above. Five sets of 30 s of WBV plus 1 DJ were performed with a rest period of 30 s between the sets [24].

Statistical analysis

Standard statistical methods were employed for calculating means and standard deviations of the dependent variables. Normality of the data was checked and subsequently confirmed by using the Kolmogorov-Smirnov test. A 2-factor (intervention × time) ANOVA with repeated measures on intervention (i.e., WBVDJ, WBV, DJ, and sham) and time (i.e., pre- and post-intervention) served to compare the jump height, power, and velocity values obtained. If significant main effects or interactions were present, Tukey's honestly significant difference post-hoc test was used to identify specific differences. To verify the sample size of the study, a statistical power calculation was performed [5]. Statistical significance of the results was accepted at $p < 0.05$. The intraclass correlation coefficient for reliability measured among the 3 pre-intervention trials of all variables ranged from 0.92 to 0.96.

Ethical approval

The research related to human use has complied with all the relevant national regulations and institutional policies, has followed the tenets of the Declaration of Helsinki, and has been approved by the University of Athens Ethics Committee (approval No.: 1369/20-4-2020).

Informed consent

Informed consent has been obtained from all individuals included in this study.

Results

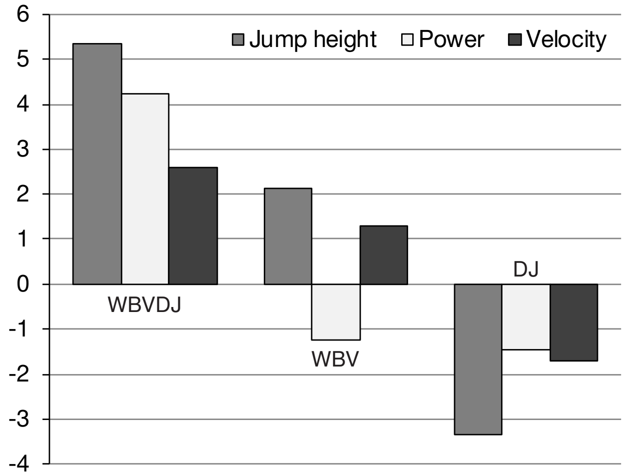
No significant difference was observed before the intervention between the different interventions for any variables. Significant intervention × time interactions were found for jump height ($F(3,27) = 6.72$; $p < 0.01$; $\eta^2 p = 0.43$; power = 0.95) and for take-off velocity ($F(3,27) = 7.05$; $p < 0.01$; $\eta^2 p = 0.44$; power = 0.96), whereas no significant interaction or main effect was identified for power. A significant increase of CMJ height between pre- and post-intervention tests was observed only for WBVDJ (4.82 ± 4.21%; $p < 0.05$; Figure 1), and the post-intervention value of the WBVDJ protocol was significantly greater than that obtained after the DJ intervention ($p < 0.01$; Figure 1).

Similarly, significant improvements of take-off velocity were found between pre- and post-intervention tests for WBVDJ (2.50 ± 2.01%; $p < 0.05$; Table 1), with the post-intervention value of the WBVDJ protocol significantly greater than that obtained after the DJ intervention ($p < 0.01$; Table 1).

Table 1. CMJ height, power, and velocity obtained before and after the WBVDJ, WBV, DJ, and sham interventions

CMJ parameter	Before intervention				After intervention			
	WBVDJ	WBV	DJ	Sham	WBVDJ	WBV	DJ	Sham
Height (cm)	27.76 ± 5.68	27.67 ± 5.74	28.04 ± 5.98	28.74 ± 5.70	29.24 ± 6.84*	28.25 ± 6.19	27.19 ± 5.79§	27.96 ± 5.04
Power (W)	698.80 ± 153.28	736.79 ± 173.85	724.14 ± 150.24	721.76 ± 160.95	728.34 ± 176.44	727.73 ± 158.29	713.62 ± 151.09	711.97 ± 152.90
Velocity (m · s^{-1})	2.32 ± 0.23	2.31 ± 0.24	2.33 ± 0.25	2.36 ± 0.23	2.38 ± 0.27*	2.34 ± 0.25	2.29 ± 0.24§	2.33 ± 0.21

CMJ – counter movement jump, WBV – whole body vibration, DJ – drop jump, WBVDJ – WBV combined with DJ, sham – no vibration
* significant increase compared with pre-intervention value ($p < 0.05$), § significantly lower value compared with pre-intervention test for WBVDJ ($p < 0.01$)



WBV – whole body vibration, DJ – drop jump,
WBVDJ – WBV combined with DJ

Figure 1. Percentage improvement in jump height, power, and velocity compared with baseline values of countermovement jump performance

Discussion

The purpose of this study was to examine the PAPE of a complex stimulus combining WBV and plyometric exercises in adult gymnasts. The main finding was that the WBVDJ intervention increased jump height of CMJ performance and the take-off velocity of lower limbs. None of the other interventions (i.e., WBV, DJ, and sham) enhanced the measured outcomes. In addition, the WBVDJ intervention led to a greater performance improvement compared with the DJ protocol. To the best of our knowledge, the results of the present study are the first to demonstrate that a complex intervention combining WBV exercise and DJs influences PAPE. So far, only Chen et al. [22] attempted to investigate the impact of different forms of complex interventions (i.e., resistance exercise and DJs, WBV and DJs) against isolated forms of interventions (i.e., resistance exercise, WBV, and DJ) upon PAPE, assessed through optimal DJ performance. Although an improvement of PAPE was observed for all interventions, no superiority of complex stimuli was reported. Numerous factors proposed recently [8] could account for the discrepant results between the present investigation and the study by Chen et al. [22]. First, the present study assessed PAPE through CMJ performance, whereas Chen et al. [22] measured DJ performance. Second, although participants performed 5 repetitions of DJs in both studies, here, the rest period was longer (i.e., 30 s vs. 5 s), which could have limited the occurrence of possible fatigue. Third, the WBV exercise extremely differed between the studies, with longer total exposure, involving dynamic movements and delivering higher theoretical vertical acceleration in the present study.

Indeed, it has been suggested that the platform acceleration is the main loading parameter of WBV exercise [11]. In fact, a WBV study using a theoretical acceleration of 197 m · s^{-2}, like the present study, reported immediately improved CMJ performance after a bout of WBV exercise comprising dynamic movements [29]. More importantly, the 4.82% increase in CMJ performance found here matches the 4.6% gain observed by Colson and Petit [17], albeit the present intervention combined WBV and DJs but had a lower total time exposure. As a remark, even if the effective vertical acceleration of the platform was not monitored as previously suggested [16, 17], a recent study provided the effective vertical acceleration of the platform used here [30], with a range of values similar to the theoretical one computed. Finally, Chen et al. [22] reported important individual PAPE responses across the interventions proposed, while in the current study all participants were responders to the WBVDJ stimulus.

None of the other interventions led to significant PAPE. This observation could be surprising since previous studies have shown that a single intervention comprising DJs [5, 8, 15, 31, 32] or WBV exercise [16–18, 33] improves CMJ performance. However, like the present study, some research failed to reveal significant improvements in CMJ performance after both the DJ [34] and WBV [17, 20, 35] interventions. Again, numerous factors related to the experimental designs implemented could account for these inconsistent observations reported in the literature, but the training background of the participants or their initial strength level also contribute to this heterogeneity [9, 36]. For example, although there was no statistically significant increase in jump height after the current WBV intervention, 6 out of 10 subjects significantly improved their performance. In turn, CMJ height was non-significantly decreased (–2.9%) after the DJ intervention, with all gymnasts exhibiting a diminution of performance. This latter observation could partly explain the significantly greater CMJ height values observed after the WBVDJ intervention compared with the DJ protocol, also emphasizing that the adult gymnasts enrolled in the present study did not positively respond to the DJ intervention proposed.

Although no neuromuscular or physiologic measures were taken to ascertain the origin of PAPE, the respective underlying mechanisms previously observed after WBV or plyometric exercise might account for the PAPE after our WBVDJ intervention. Previous studies have shown that WBV or DJ interventions were able to induce the PAP phenomenon through increases in twitch force [1, 13, 14], possibly owing to myosin regulatory light chain phosphorylation. However, it is unlikely that this mechanism could contribute to the PAPE observed in our post-intervention evaluations performed 8 min after WBVDJ. Indeed, it has been recently underlined that twitch force declines exponentially over 8 min after an intervention [37]. In the context of spinal excitability facilitation observed after WBV exercise [38, 39], an increased neural activation could be another potential candidate for PAPE. Nevertheless, spinal excitability facilitation was only noted at rest, whereas it was not the case during muscle contraction [39]. In addition, muscle voluntary activation was non-potentiated [14] or even decreased after an acute WBV exercise [6]. Consequently, this lack of immediate neural facilitation after WBV questions the possible influence of greater neural activation on PAPE after WBVDJ. Similarly, an increase in muscle-tendon or lower limb muscle stiffness should in theory promote PAPE. Although a recent study indicated that DJs potentiated leg-spring stiffness [40], such observations were not reported after WBV exercise [12, 17]. Considering that the DJ intervention proposed in the current study led to a non-significant decrease of performance, it is unlikely that lower limb muscle stiffness could account for the PAPE implied after WBVDJ.

It has been suggested that PAPE comprising 1–5%, as in the present study, could be largely explained by an increase in muscle temperature, mainly when muscle-shortening contractions are required [38], like during a CMJ performance. Indeed, previous research showed that muscle temperature increased more during an exercise with WBV compared with the same exercise without WBV [29] and that a WBV dynamic squatting exercise aimed at increasing muscle temperature led to CMJ improvements [41]. In this latter study, however, the increases in CMJ performance were not fully explained by muscle temperature: rises in muscle blood flow were also suggested to account for performance improvements. Increases in blood flow could theoretically enlarge Ca^{2+} sensitivity. If present, this mechanism could increase muscle fibre force and shortening velocity. Considering the improved take-off velocity during the CMJ of the present WBVDJ intervention and the enhanced blood flow reported during WBV exercise [33], it might be speculated that this mechanism could contribute to the PAPE observed after WBVDJ.

The current study has some limitations and the results obtained should be interpreted with caution. First, the results are specific to adult gymnasts, as well as to the characteristics of the interventions proposed (e.g., type of platform used, theoretical acceleration chosen, sets, repetitions). Second, even if muscle temperature was not controlled as suggested [37], the sham intervention did not improve PAPE. Then, and although previous WBV studies evidenced some of the possible underlying mechanisms of PAPE, no physiologic or neuromuscular measures were investigated here.

Conclusions

The results of the present study indicate that a complex stimulus combining WBV and plyometric exercise (i.e., DJ) may induce a PAPE response, resulting in an improvement in CMJ height and take-off velocity. The extent of PAPE was comparable with that in previous reports in the literature after other forms of intervention [9, 13]. All participants responded to the proposed intervention, which suggests that the combined WBV and DJ bouts could be applied as a PAPE exercise in gymnasts.

The present findings have valuable implications for designing interventions aimed at inducing the PAPE phenomenon, especially when considering CMJ performance. The utilization of a complex intervention combining WBV and DJs produces an acute enhancement of CMJ performance (i.e., 8 min after the intervention). This type of intervention constitutes a successful stimulus that could be implemented in athletes requiring jump performance in their sport. In addition, owing to its duration, it is suggested that trainers could integrate this kind of intervention during the half-time period in team sports for re-warm-up purposes.

Disclosure statement

No author has any financial interest or received any financial benefit from this research.

Conflict of interest

The authors state no conflict of interest.

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