ORIGINAL ARTICLE

Effects of plyometric warm-up performed with different resistances on jumping performance as post-activation potentiation

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ABSTRACT

The purpose of this study was to investigate the effect of plyometric warm-up with different resistances as post activation potentiation stimulus on vertical jump performance. Fifteen athletes from short and middle distance branches of athletics who have been training regularly for at least 5 years and at least 5 days a week attended the study voluntarily. The athletes in this study were warmed up for 5 minutes at a speed of 8 km/h on a treadmill, followed by 5 minutes of passive rest. Completing 5 minutes of passive rest, the athletes were randomly sampled and any of the 50 lb, 60 lb, 70 lb, 80 lb resistance or non-resistance warm-up protocols consisting of 3 sets on the vertimax device were carried out. After warming up, 5 minutes of passive rest was given and then squat jump (SJ) and countermovement jump tests were performed. Repeated measures ANOVA test was conducted in the analyses of the measurements of jump distance and power of the athletes participating in this study both without resistance and after the applied resistances. As a result of the analysis, significant differences were observed in SJ and CMJ values after PAP warm-up without and with resistance ($p < .05$). The height and power values of SJ after PAP warm-up with 70 lb and 80 lb resistance bands were found significantly higher than those without resistance ($p < .05$). Furthermore, the height and power values of CMJ after PAP warm-up with 80 lb resistance bands were found significantly higher than the values of warm-up without resistance ($p < .05$). In conclusion, even though an increase in jump height and power values was observed with each resistance increment, significant increases in power and height values as a PAP response were achieved at 70 and 80 lb resistance for SJ and 80 lb resistance for CMJ.

Keywords: Performance analysis, Post activation potentiation, Jump, Resistance.

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INTRODUCTION

Warm-up is a widely used exercise before nearly all athletic activities (Bishop, 2003). In this regard, warm-up practices, which are deemed as a critical factor, are routinely utilised by athletes to prevent injuries and reach high performance in training and competition (Sotiropoulos, 2014). Additionally, multiple physiological and neural mechanisms have been assessed to determine the contribution of warm-up to performance and responses to different warm-up strategies, which have been reported to include augmented muscle metabolism, high oxygen uptake (VO_2) kinetics and post activation potentiation (PAP) (Mcgowan et al., 2015).

Post activation potentiation is the transient increment in the contractile performance of the muscle following a prior contractile activity (Sale, 2002). PAP, typically resulting from a voluntary contraction performed at or very close to maximal intensity (Tillin and Bishop, 2009), signifies the phenomenon of an acute gain in muscle strength as a result of a history of contraction (Robbins, 2005). It has been claimed that two basic mechanisms are responsible for PAP. One of these is the phosphorylation of myosin regulatory light chains and the second is the increased activation of motor units at a higher rate. Nevertheless, it has been stated that changes in the penetration angle may also contribute to the PAP response (Tillin and Bishop, 2009).

In the literature, resistance training (Chatzopoulos et al., 2007; Chıu et al., 2003; Villalon-Gasch et al, 2020; Mitchell and Sale, 2011; Seitz et al., 2014) and plyometric activities (Ciocca et al., 2021; Turner et al., 2015; Tobin and Delahunt, 2014; Johnson et al., 2019) are frequently chosen as preconditioning stimulus in studies that aim to boost performance with PAP. Despite the fact that intensities of 60% 1 RM and above are sufficiently high for the PAP effect to occur in resistance applications (Kobal et al., 2019; Smilios et al., 2005), it has been indicated that higher effects can be seen at intensities of 85-90% 1 RM (Garbisu-Hualde and Santos-Concejero, 2021). Besides, plyometric activities are a variation of dynamic movements that are integrated into warm-up routines to generate a PAP stimulus and hence strengthen the force building capacity of the muscle (Johnson, 2019). It has been pointed out that a plyometric activity stimulus might have the potentiation to induce a PAP response similar to a weighted resistance stimulus (Tobin and Delahunt, 2014). Thus, plyometric protocols may be preferred as an ideal PAP stimulus since they efficiently strengthen the muscle with less fatigue than traditional weight-based protocols (Johnson et al., 2019).

Furthermore, plyometric activities have been seen to enhance physical performance more than weighted resistance training in terms of PAP response (Sharma et al., 2018). Nonetheless, further studies are needed to support this finding. Although PAP responses following weighted resistance protocols have been broadly studied (Chatzopoulos et al., 2007; Chıu et al., 2003; Villalon-Gasch et al., 2020; Mitchell and Sale, 2011; Seitz et al., 2014; Kobal et al., 2019; Smilios et al, 2005), there are limited number of studies examining the PAP effect following a plyometric stimulus (Ciocca et al., 2021; Turner et al., 2015; Tobin and Delahunt, 2014; Johnson et al., 2019; McBride et al., 2005; Till and Cooke, 2009). Even though there are studies showing an impact on performance during the process using plyometric activities as PAP stimuli (Turner et al., 2015; Tobin and Delahunt, 2014; Ciocca et al., 2021), there are also studies showing no effect (Till and Cooke, 2009; McBride et al., 2005). This inconsistency among studies might be attributed to methodological differences and variability in individual characteristics (training history, gender, muscle fibre type, recovery time after PAP stimulus, etc.). One of the methodological approaches using plyometric activities as PAP stimuli is plyometric activity include resistance. Though the contribution of plyometric activities to performance in terms of PAP response has been noted in some studies (Tobin and Delahunt, 2014; Ciocca et al., 2021), it has been obtained that plyometrics performed with resistance have an extra contribution to athletic performance (Turner, 2015). However, to the best of our knowledge, there is not any study in the literature that examines the effect of PAP stimulus on athletic performance in plyometric activities performed with resistance in terms of the amount of load used. Thus, the purpose of this study was to investigate the effects of plyometric warm-up with different resistances as PAP stimulus on vertical jump performance.

METHODS

Participants

Fifteen athletes (age: 20.13 ± 3.20 years; height: 175.60 ± 8.75 cm; body weight: 70.69 ± 15.94 kg) from the short and middle distances of athletics, who have been training regularly for at least 5 years and at least 5 days per week, voluntarily participated in this study. Prior to the start of the study, the athletes were instructed about both the study and progress and signed an informed consent form. Participants were asked to refrain from intense physical activity, to adjust their sleep patterns, and to refrain from using stimulants or alcohol for 24 hours prior to the start of the tests. Previously, before the beginning of the tests, the height and body weight of the athletes were measured. Measurements were carried out between 15:00 and 18:00. The study was approved by the Social and Human Sciences Ethics Committee of Kütahya Dumlupınar University (dated 04.09.2023 and number 334).

Body weight and height measurements

Body weights of the athletes were measured at least 2 hours after the meal in shorts, T-shirt and bare feet using a scale (Tanita HD 358, Tokyo, Japan) with a sensitivity of 0.1 kg. Height was determined with a wall mounted stadiometer (Holtain Ltd. U.K.) with an accuracy of 1 mm in the anatomical posture and with the head in the Frankfort plane, barefoot.

Jump measurements

The measurements of SJ and CMJ of the athletes in the study were detected with a device (FitJump, Türkiye) that monitors the jump height depending on the duration of stay in the air (with a sampling frequency of 1000 Hz) through a photoelectric sensor located on the ground. The data which were obtained from the device were transferred to the computer software programme (fitjump-v1.0) via Bluetooth.

Test procedure

Within the content of the study, body weight and height measurements were performed before PAP warm-up protocols and test administrations at the first arrival of the athletes to the laboratories. Additionally, they were briefed about the study and allowed to make a trial to get used to the warm-up protocols. The following day after the trial phase, all athletes were invited to the laboratory again. Prior to each PAP warm-up protocol, the athletes performed a 5-min warm-up on a treadmill (Proforce Q3, China) at a speed of 8 km/h, immediately preceded by a 5-min passive rest. Subsequently, a warm-up protocol consisting of 3x10 repetitions (1 min rest between sets) with 4 different resistance loads (50 lb, 60 lb, 70 lb and 80 lb) was performed to create a PAP stimulus. The athletes completed the resistive PAP warm-up protocols involving vertical jumping on the vertimax device in a randomised manner and at 48 hours intervals. After the PAP warm-up protocols with different resistances, athletes were provided with a passive rest for 5 min and SJ and CMJ tests were performed immediately later. During the vertical jump tests, the midpoint of the athletes' feet was centred in front of the photoelectric sensor in the sagittal plane. SJ tests were carried out with maximal force after waiting 3-5 s with hands on waist, trunk in upright position and knees in ~ 90° flexion. CMJ tests were done with maximal power without a pause after hands on waist, trunk in upright position and knees in ~ 90° flexion. Each vertical jump test (SJ and CMJ) was repeated twice with 30 s passive rest breaks and the best score was assessed as the measurement outcome. On the other hand, in the non-resistance warm-up protocol, the athletes performed a 5-min warm-up on the treadmill at a speed of 8 km/h and immediately afterwards

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they performed a passive rest for 5 min. Following the rest, they were subjected to SJ and CMJ tests. The workflow diagram of the study is visualised in Figure 1.

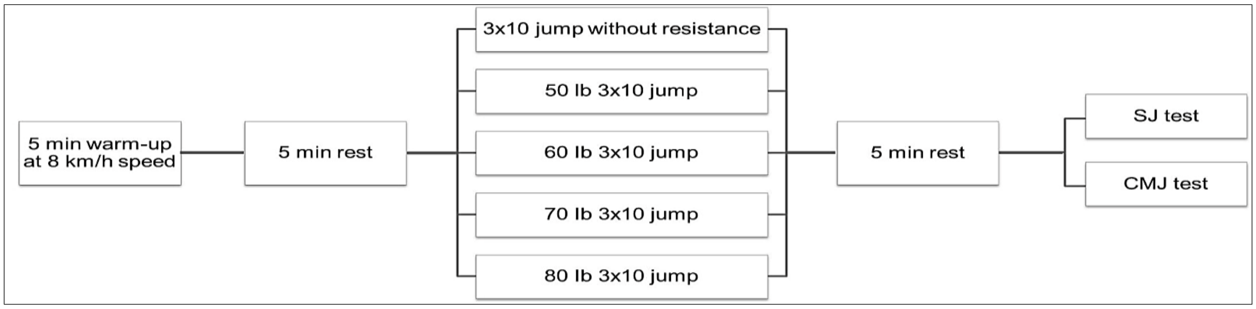

Figure 1. Workflow diagram for non-resistive and resistive PAP warm-up.

Statistical analysis

Kolmogorov-Smirnov (KS) test was utilised to determine if all variables of the athletes who participated in the study had a normal distribution. Results of the analysis showed that all of the variables had normal distribution ($p > .05$). Repeated Measures of ANOVA (Repeated Measures of ANOVA) test was used for the analysis of the measurements of jump height and power of the athletes (SJ and CMJ) participating in the study after non-resistance and resistance PAP warm-up protocols. Bonferroni correction was applied for multiple comparisons among different resistances. Significance level was acceptable as $p < .05$.

RESULTS

The findings of SJ height and power values of the athletes participating in this study after warm-up without resistance and PAP warm-up with 50 lb, 60 lb, 70 lb, 80 lb resistance consisting of 3x10 repetitions are listed in Table 1.

Table 1. SJ values of athletes for non-resistance warm-up and PAP warm-up protocols with resistance.

Variables	**n**	**Non-resistive warm-up**	**Resistances PAP warm-up**				**F**
			50 lb	60 lb	70 lb	80 lb	
		Mean±SD	Mean±SD	Mean±SD	Mean±SD	Mean±SD	
SJ height (cm)	15	35.14±7.18^{a,b}	36.44±7.48	37.82±6.03	37.98±6.87^{a}	38.59±6.24^{b}	4.708*
SJ power (watt)	15	914.11±264.25^{c,d}	932.16±276.24	949.63±261.24	951.10±265.58^{c}	956.71±255.23^{d}	7.774*

*Note. * a,b,c.d = p < .05 statistical differences at significance level.*

Based on the statistical analysis, it was observed that there were significant differences in SJ height and power values after PAP warm-up without resistance and PAP warm-up with resistance ($p < .05$). After PAP warm-up which were performed with 70 lb and 80 lb resistance bands, SJ height and power values were found to be significantly higher than the non-resistance warm-up values ($p < .05$).

The results of CMJ height and power values of the athletes participating in this study after warm-up without resistance and PAP warm-up with 50 lb, 60 lb, 70 lb, 80 lb resistance made up of 3x10 repetitions are presented in Table 2.

Table 2. CMJ values of athletes for non-resistance warm-up and PAP warm-up protocols with resistance.

Variables	**n**	**Non-resistive warm-up**	**Resistances PAP warm-up**				**F**
			50 lb	60 lb	70 lb	80 lb	
		Mean±SD	Mean±SD	Mean±SD	Mean±SD	Mean±SD	
CMJ height (cm)	15	37.42±6.49[a]	38.72±6.15	38.73±7.03	39.54±5.94	40.95±6.32[a]	3.615*
CMJ power (watt)	15	944.42±270.11[b]	960.85±269.03	961.19±275.44	969.69±261.98	985.43±261.16[b]	2.968*

*Note. * a,b = p < .05 statistical differences at significance level.*

The results of the statistical analysis determined that there were significant differences in CMJ height and power values after PAP warm-up without resistance and PAP warm-up with resistance ($p < .05$). CMJ height and power values after PAP warm-up with 80 lb resistance bands were notably higher than those after warm-up without resistance ($p < .05$).

DISCUSSION

In this research, it was attempted to investigate the effect of plyometric warm-up performed with different resistances as PAP stimulus on vertical jump performance scores. The major finding of this study was that plyometric warm-up performed with higher resistances caused a significant rise in SJ and CMJ height and power values. According to this study, after plyometric warm-up protocols performed with different resistances (50 lb, 60 lb, 70 lb, 80 lb) as PAP stimulus, linear increase in SJ and CMJ values with loading increase [(50lb = 3% for SJ height. 7%, 60lb = 7.6%, 70lb = 8.1% and 80lb = 9.8% for SJ height) (50lb = 3.5%, 60lb = 3.5%, 70lb = 5.7% and 80lb = 9.4% for CMJ height)], yet this increase was significant at higher resistances (70 and 80 lb for SJ, 80 lb for CMJ; $p < .05$).

The intensity of resistance is one of the critical factors affecting PAP responses. In this regard, high loads (1 RM > 85%) have been prioritised (Bevan et al, 2010; Boullosa et al, 2013; de Villarreal et al, 2007) in studies conducted to evaluate the intensity of resistance used as a PAP stimulus (generally in weight training). In a systematic review, it was mentioned that high volume and moderate intensity (65% 1RM) PAP warm-up protocols performed with weights can also improve performance, but warm-up performed at high loads (85-90% 1RM) could be more beneficial if longer rest intervals are given (Garbisu-Hualde and Santos-Concejero, 2021). In addition, it has been reported that the similarity of the movements applied in PAP warm-up with the movements to be practised after warm-up may favourably affect performance (Suchomel et al., 2016). In this respect, plyometric activities were analysed as PAP stimuli in order to improve power activities by taking into cognisance their kinematic similarity to the subsequent performance (Ciocca et al., 2021; Turner et al., 2015; Maloney et al., 2014; Till and Cooke, 2009; Kilduff et al., 2007).

In several studies that have used plyometric activities as PAP stimuli, jumps consisting of different sets, repetitions and methods have been employed (Ciocca et al., 2021; Turner et al., 2015; Maloney et al., 2014; Till and Cooke, 2009; Kilduff et al., 2007; McBride et al., 2005). In some of the conclusions obtained from these studies, it was noted that plyometric warm-up as a PAP stimulus increased subsequent performance (Ciocca et al., 2021; Turner et al., 2015; Tobin and Delahunt, 2014), while in others it was reported that there was no significant effect (Till and Cooke, 2009; McBride et al., 2005). Nonetheless, it is useful to keep in mind some variables in order to achieve improvement in performance after PAP stimulus. It has been specified that the type of exercise, recovery time between PAP stimulus and performance, muscle fibre type, gender, fitness level, the structure of the applied test protocol (Chatzopoulos et al., 2007), warm-up intensity, volume,

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etc. can be effective on performance enhancement after PAP warm-up (Suchomel et al., 2016; Chatzopoulos et al., 2007).

Looking at the studies using plyometric activities as PAP stimuli, it is clear that different protocols are applied, including resistant (Turner et al., 2015; McBride et al., 2005) and non-resistant (Ciocca et al., 2021; Sharma et al., 2018; Turner et al., 2015; Tobin and Delahunt, 2014; Till and Cooke, 2009) plyometrics. In cases where non-resistance plyometric activities are preferred as PAP stimulation, there are studies reporting that they have an effect on performance (Ciocca et al., 2021; Sharma et al., 2018; Turner et al., 2015; Tobin and Delahunt, 2014) as well as studies reporting that they do not (Till and Cooke, 2009). In a study conducted with rugby players, Tobin and Delahunt (2014) examined that a total of 40 jumping exercises including a series of different plyometric activities (ankle/hurdle hops and drop jumps) increased CMJ height and power. Till and Cooke (2009) examined the effects of PAP warm-up consisting of dynamic (plyometric and weight) and maximal isometric contraction (MVC) protocols on sprint and vertical jump performance and found that plyometric warm-up (1x5 repetition tuck jump) did not have a meaningful influence on sprint and vertical jump performances. Nevertheless, the researchers have emphasised that PAP is to be evaluated individually owing to the wide differences in individual responses in this study (Till and Cooke, 2009).

Besides, it has been reported that performance outcomes may vary according to whether or not additional load is used in plyometric exercises in terms of PAP response (Turner et al., 2015). Turner et al. (2015) examined the effects of warm-up protocols including unloaded and loaded plyometric activities as PAP stimuli on sprint performance in their studies. They found that alternate-leg bounding conducted with body and additional weight of 10% of body weight markedly improved 10 m and 20 m sprint performance. Moreover, they have shown that the loaded (10% body weight) plyometric warm-up protocol had a superior effect on sprint performance in terms of PAP response in comparison to the unloaded protocol. Similarly, McBride et al. (2005) reported that a loaded (30% of 1 RM) multiple jump stimulus consisting of 1x3 repetitions had no efficacy on sprint performance. At this point, it is worth considering whether the amount of workload used during plyometric warm-up has an adverse effect on subsequent performance. This suggests that the amount of load used during plyometric warm-up, as in weighted warm-ups, might also have an effect on subsequent performance. During our study, despite the increase in vertical jump height and power values with the increase in the amount of resistance used during plyometric warm-ups, this increase was meaningful at relatively high resistances. Regarding the joint effect of volume and intensity, it is stated that the activation of type II muscle fibres is essential to elicit a PAP response in sportive performance (Sirieiro et al., 2021, Maloney et al., 2014). Therefore, it has been found that the neural stimulation obtained after heavy loads is higher in type II muscle fibres (Sirieiro et al., 2021; Hamada et al., 2000; Parry et al., 2008), and it has also been noted that low loads cannot be nearly as effective as high loads for more motor units to be activated (Schoenfeld et al., 2010). Hence, the use of high loads is generally prescribed to obtain a greater PAP response due to the increased engagement of higher threshold motor units stimulating type II muscle fibres (Sirieiro et al., 2021; Seitz et al., 2014). The results of the current study also confirmed that warm-up protocols using higher resistances were more successful in terms of promoting PAP stimulus.

This study was conducted on male athletes and no comparison was made in terms of gender. It is reported that one of the factors that the effect of PAP warm-up on subsequent performance is gender (Tsolakis et al., 2011; Terzis et al., 2009). In this respect, one of the limitations of this study is that the participant group consists of only male athletes. In addition, the structure of muscle fibres is reported as another factor affecting the PAP response. It is stated that type II muscle fibres increase performance outputs in terms of PAP response more than type I muscle fibres (Hamada et al., 2000). Another limitation of our research is that the effects of muscle fibre type on power parameters in terms of obtaining PAP response are not taken into account. It can be evaluated in further studies in terms of the effects of gender and muscle type distribution on performance outcomes in plyometric warm-up with different resistances as PAP stimulus.

CONCLUSION

In conclusion, whereas each resistance level used in this study (50 lb, 60 lb, 70 lb and 80 lb) caused a linear increase in vertical jump height and power values, this increment was significant at higher resistance levels (70 and 80 lb for SJ and 80 lb for CMJ). Consequently, the evidence from this study demonstrated that the amount of load used in resistance plyometric warm-up is influential in terms of producing a PAP effect on subsequent performance. Considering the amount of load used in resistance plyometric warm-up would be more appropriate in terms of PAP effect.

AUTHOR CONTRIBUTIONS

Halit Harmancı: collection of data, taking measurements, carrying out statistical analysis and writing the article. Pınar Demirel: collection of data, taking measurements, writing the article. Harun Koç: Collection of data, taking measurements, writing the article. Recep Tekin: Collection of data, taking measurements, writing the article. All authors read and approved the final version of the manuscript.

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No potential conflict of interest was reported by the authors.

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