

Acute effects of two different active warm-up strategies on vertical jump and running performance

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Abstract

The current study aimed to analyze and compare the effects of two different active warm-up strategies (general warm-up vs. specific warm-up using plyometric exercises), on power and running performance. Nine healthy adult males, age 29.89 ± 6.99 years, weight 79.59 ± 7.66 kg, and height 175.22 ± 7.17 cm, participated in two sessions in a random order in a crossover format. After familiarization with the experimental procedures and with countermovement jump (CMJ) and squat jump (SJ), participants were randomly assigned to general (GW) or specific (using plyometric exercises - PW) warm-up protocols prior to a 1,000 meter running exercise. CMJ and SJ tests were performed before and after the warm-up protocols and the jump height was computed. The time to perform the 1,000 meter running exercise was reported. The main results showed an effect for time ($p < .01$), but not an interaction ($p = .19$) or condition effect ($p = .56$) for CMJ. The SJ showed time ($p < .01$) and interaction effects ($p < .05$), but no condition effect ($p = .62$). Paired comparisons showed that SJ increased post GW ($p < .01$) compared to pre, but did not change post PW ($p = .36$). No difference was found in running time when the two warm-up strategies were compared ($p = .66$). In conclusion, the general warm-up promoted a pronounced improvement in the subsequent power test, but no differences were found between the general and specific warm-ups on performance in the subsequent running exercise. The results of this study should be analyzed with some caution, and when using PW to improve performance, it should be individualized with adequate volume.

Keywords – Plyometrics, Post-Activation Performance Enhancement, Exercise, Power, Running.

Introduction

Warming-up prior to training and competition is a routine of sports and exercise practitioners (Bishop, 2003b, 2003a; McGowan et al., 2015), performed to prepare the organism for the main activity, and to achieve optimal physical performance (Bishop, 2003b, 2003a; McGowan et al., 2015; Woods et al., 2007). The warm-up can be executed using passive or active techniques (Bishop, 2003b, 2003a). While a passive warm-up is performed using an external heat source or technique (i.e., hot showers or baths, saunas, diathermy, and heating pads) without any physical activity, an active warm-up is characterized by the use of pre-conditioning exercises (PCE) (Bishop, 2003b, 2003a; Silva et al., 2018). The PCE adopted may be characterized as a general warm-up when involving non-specific actions, normally actioning large muscle groups (i.e., jogging, calisthenics, cycling, and swimming), or as a specific warm-up when using similar movements or body parts to those involved in the subsequent exercise or main activity (Shellock & Prentice, 1985).

The structure of the PCE during warm-up is suggested as essential to achieve the expected results and may differently impact subsequent tasks with different characteristics (i.e., Short-term maximal effort ≤ 10 s; Intermediate maximal effort > 10 s and < 5 min; Long-term maximal effort ≥ 5 min)(Bishop, 2003a). This may be related to the mechanisms triggered (McGowan et al., 2015). A general warm-up is performed in order to raise muscle and body temperature (Bishop, 2003b; Faulkner et al., 2013; McGowan et al., 2015), which is accompanied by an increase in muscle metabolism (Gray & Nimmo, 2001) and muscle fiber conduction velocity (McGowan et al., 2015; Murakami et al., 2014). Previous studies showed that a general warm-up improved performance in short-term maximal effort activities (Andrade et al., 2015; Bishop, 2003a; Pagaduan et al., 2012). Furthermore, when associated with increased baseline oxygen consumption (Bishop, 2003a), a general warm-up may improve long-term and intermediate maximal effort performance (Bishop, 2003a; Grodjinovsky & Magel, 1970). PCE characterized as a specific warm-up has been used with the aim of promoting post-activation performance enhancement (PAPE) (Bishop, 2003b; Blazevich & Babault, 2019; McGowan et al., 2015). PAPE is an acute enhancement in voluntary muscular performance as a result of a previous high-intensity voluntary conditioning contraction (Blazevich & Babault, 2019). The term PAPE was proposed by Cuenca-Fernández et al., (2017) to distinguish the performance enhancement in voluntary exercises (PAPE) from enhancement in muscle twitch response (post-activation potentiation – PAP) reported post PCE. It has been proposed that PAPE could promote phosphorylation of myosin regulatory light chains (at least in the earliest stages), increase fluid

changes in muscles, and increase muscle activation (Blazevich & Babault, 2019). PAPE has been reported after isometric (Spieszny et al., 2022) and dynamic exercises (Seitz & Haff, 2016), and the magnitude of performance enhancement is related to the level of strength and experience in strength training. Considering the aforementioned, a practical possibility could be the use of plyometric exercises in order to promote PAPE and improve power output (Barreto et al., 2023; Krzysztofik & Wilk, 2020; Tobin & Delahunt, 2014). This possibility is raised based on a previous systematic review with meta-analysis that showed small improvements in jump, sprint, throw, and upper-body ballistic performances when preceded by plyometric exercises (Seitz & Haff, 2016). Despite differences in the related mechanisms (Bishop, 2003b; Blazevich & Babault, 2019; Faulkner et al., 2013; McGowan et al., 2015), both general (Andrade et al., 2015; Bishop, 2003a; Pagaduan et al., 2012) and specific warm-ups (Seitz & Haff, 2016; Krzysztofik & Wilk, 2020; Tobin & Delahunt, 2014), specifically using plyometric exercises, may improve power performance. Furthermore, although the improvement in long-term and intermediate maximal effort performance is more frequently reported when a general warm-up is performed (Bishop, 2003a; Grodjinovsky & Magel, 1970), this improvement has also been suggested for specific warm-ups (aiming to promote PAPE) (Blagrove et al., 2019; Boullosa et al., 2018; Low et al., 2019; Wei et al., 2020). Therefore, with the objective of helping coaches and practitioners understand and choose the PCE, the aim of the current study was to analyze and compare the effects of two different active warm-up strategies; one general and another specific, performed using plyometric exercises, on power and running performance in healthy adult men. Despite differences in the related mechanisms (Bishop, 2003b; Blazevich & Babault, 2019; Faulkner et al., 2013; McGowan et al., 2015), it was hypothesized that both warm-up strategies would promote similar improvement in muscle power and running performance.

Methods

Participants

In total, nine men participated in this study, aged 29.89 ± 6.99 years, body mass 79.59 ± 7.66 kg, and height 175.22 ± 7.17 cm. The inclusion criteria were: self-declared healthy adult men; nonsmokers; not presenting diabetes, hypertension, or coronary artery disease; not using medicines that could compromise the results; not presenting any condition that may prevent participation in physical activity; and practicing at least 150 min of moderate physical activity per week. The exclusion criteria were: musculoskeletal injuries or missing data collection days. Participants who met the inclusion criteria signed an informed consent term, agreeing to voluntarily participate in the study. The study was approved by the Human Research Ethics Committee (CAAE: 51101021.0.0000.5531; n° 5.115.631).

Study Design

This is a crossover study with a randomized-controlled design. Participants were randomized and allocated to two different warm-up interventions: a general warm-up (GW) or a specific warm-up using plyometric exercises (PW). The participants visited the laboratory twice, 7 days apart.

To compare the effects of GW and PW strategies, all participants performed counter-movement jumps (CMJ) and squat jumps (SJ) before and after the warm-up protocols and a 1,000 meter running exercise. On the first day, four participants performed GW and five performed PW and on the second day the protocol performed was inverted. Familiarization was performed before each experimental day with 3 submaximal counter-movement jumps (CMJ) and 3 submaximal squat jumps (SJ). CMJ and SJ tests were performed before and after the warm-up interventions. After the warm-up interventions, participants rested for 10 min in a seated position before executing the post CMJ and SJ tests and immediately performed an all-out 1,000 meter running exercise (Figure 1).

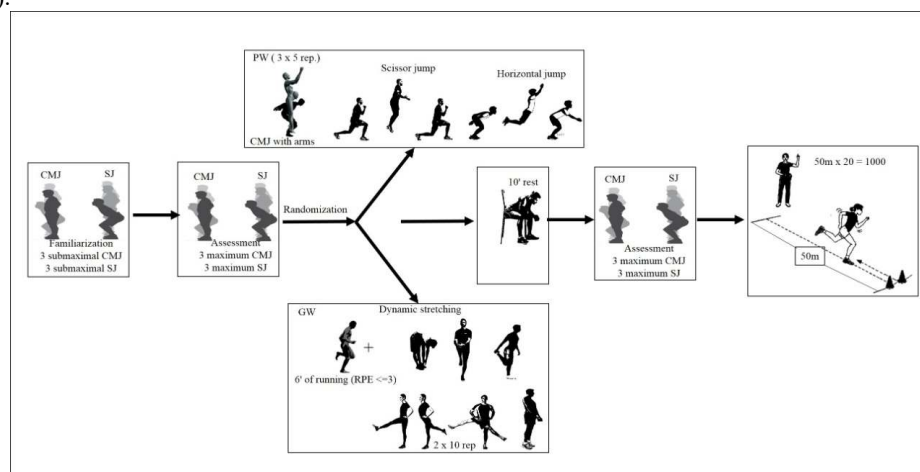


Figure 1. study design. PW = plyometric warm-up, GW = general warm-up, CMJ = countermovement jump, SJ = squat jump, RPE = rating of perceived exertion.

Warm-up protocols

Both interventions were performed for ~10 minutes. The GW was composed of 6-minutes of walking/jogging with an intensity based on a rating of perceived exertion value of 2-3 (0-10 Borg scale (Borg, 1990)) followed by 2 x 10 reps of dynamic stretching, including: toe touch; standing hip flexor; standing quad stretch; front to back leg swing, side to side leg swing; and standing calf stretch. The PW consisted of 3 plyometric exercises: CMJ, scissor jump, and horizontal jump (3 x 5 rep) intercalated with 1 min of rest.

Vertical jump tests

CMJ and SJ Tests were performed using the New Fit Jump System (Cefise, São Paulo, BR), which is equipment developed to measure ground contact time and flight time in vertical jumps. For the CMJ, the participant started from the orthostatic position, performed a squat with a stretch-shortening cycle, and then immediately performed a jump. For the SJ, participants started from a squat with a knee flexion of approximately 90° and performed the jump. Three CMJ and SJ were performed with arms akimbo, respecting a 15 second interval between attempts. The participants were instructed to perform a maximum vertical jump and received motivational stimuli through verbal encouragement (Vasconcelos et al., 2020). The average jump height of the 3 jumps was determined as a performance variable.

1,000 meter run

The time that participants took to perform an all-out 1000 meter run was measured. For this, participants performed 20 x 50 meters of linear running with a 180° change of direction, on an asphalt track, without inclination. The participants received motivational stimuli through verbal encouragement (Vasconcelos et al., 2020).

Statistical analysis

Data normality was confirmed by the Shapiro Wilk test. The paired Student's t test was used to compare running time. The two-factor (time and condition) generalized estimation equation technique adjusted by the Bonferroni test was performed for between, within, and interaction comparisons (condition x moment) of CMJ and SJ. All analyses were performed in SPSS (IBM® SPSS® Statistics 21). The level of significance adopted was $P < .05$. The effect sizes (ES: Cohen's $d = (\text{mean } 2 - \text{mean } 1) / \text{standard deviation } 1$) of time and condition (only for running time) comparisons were measured, interpreted as follows: $d (.01) = \text{very small}$, $d (.2) = \text{small}$, $d (.5) = \text{medium}$, $d (.8) = \text{large}$, $d (1.2) = \text{very large}$, $d (2.0) = \text{huge}$ (Sawilowsky, 2009).

Results

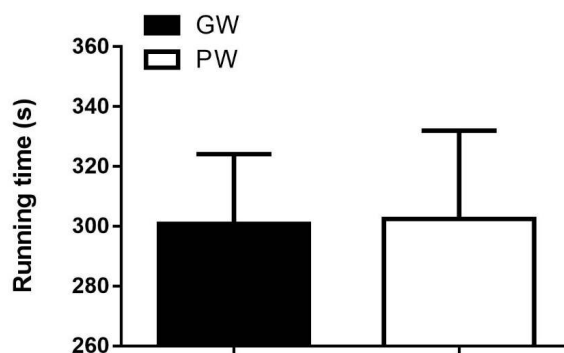
The CMJ and SJ results are reported in Table 1. CMJ showed a time effect ($P < .01$) but no interaction ($P = .19$) or condition effect ($P = .56$). SJ showed time ($P < .01$) and interaction effects ($P < .05$), but no condition effect ($P = .62$). The paired comparisons demonstrated that SJ increased post GW ($P < .01$) compared to pre but did not change post PW ($P = .36$).

The running time (Graph 1) post GW was 300.67 ± 23.48 seconds and post PW was 302.44 ± 29.48 seconds. There was no difference in running time when comparing the two warm-up strategies ($P = .66$).

Table 1 – Countermovement jump and squat jump results at pre and post moments for general (GW) and specific (PW) warm-ups.

Variable	Condition	an $\pm$ SD)	Post (mean $\pm$ SD)	P (time)	P (group)	P (interaction)
CMJ (cm)	GW	34.79 $\pm$ 4.80	36.77 $\pm$ 4.83	< .01	.56	.19
	PW	34.02 $\pm$ 6.23	34.74 $\pm$ 6.03			
SJ (cm)	GW	33.10 $\pm$ 4.09	35.51 $\pm$ 5.44*	< .01	.62	.048
	PW	33.00 $\pm$ 4.96	33.41 $\pm$ 5.69			

CMJ = countermovement jump; SJ = squat jump; GW = general warm-up; PW= specific warm-up performed using plyometric exercises. * Difference from pre-value ($P < .05$).



Graph 1. Time to perform the all-out 1,000 meter running exercise after general (GW) and specific (PW) warm-ups.

The ES results for CMJ, SJ, and time to perform the all-out 1,000 meter running exercise are reported in Table 2. For GW the ES of the pre-post comparison of CMJ was small and for SJ this comparison was medium. For PW the ES of the pre-post comparison of CMJ was very small and for SJ it was null. The ES of between group comparisons of time to perform the all-out 1,000 meter running exercise was null.

Table 2 – Effect size (Cohen's d) of pre and post comparisons of Countermovement jump and Squat jump performed before and after the general (GW) and specific (PW) warm-ups and of between group comparisons for time to perform the 1,000 meter running exercise.

Variable	Condition	Cohen's d	Classification
CMJ (cm)	GW	.41	Small
	PW	.12	Very small
SJ (cm)	GW	.59	Medium
	PW	.08	Null
Running time (s)	GW x PW	.08	Null

CMJ = countermovement jump; SJ = squat jump; GW = general warm-up; PW= specific warm-up performed using plyometric exercises.

Discussion

The main results found were that both general and specific warm-up protocols improved performance in the CMJ test but only the general warm-up improved performance in the SJ. Furthermore, pronounced effect sizes were reported in both vertical jump tests after the general warm-up. No difference between warm-up protocols was found for change in performance in the 1,000 meter running exercise. These results accept the hypothesis raised, since both warm-up protocols improved performance in the lower limb muscle power tests but refute the hypothesis by showing better results for the general warm-up.

Despite the differences in the reported mechanisms (Bishop, 2003b; Blazevich & Babault, 2019; Faulkner et al., 2013; McGowan et al., 2015), both general and specific warm-up protocols improved performance in the vertical test. The improvement in subsequent power activities after the general warm-up was expected and is in accordance with results shown previously (Andrade et al., 2015; Bishop, 2003a; Pagaduan et al., 2012). The results found may be justified by the similar structure of the PCE to that suggested in a previous review (i.e., PCE with 5-10 minutes of moderate intensity followed by 5 minutes of recovery) (Bishop, 2003a). This dose of PCE is related to improvement in muscle temperature, the principal mechanism suggested to improve short-term maximal effort activities (Bishop, 2003b, 2003a; McGowan et al., 2015).

Corroborating previous studies (Seitz & Haff, 2016; Krzysztofik & Wilk, 2020; Tobin & Delahunt, 2014), the results in the CMJ test suggest that the specific warm-up also improved performance in subsequent power activities. However, this kind of PCE did not improve SJ results. These results may be better interpreted based on the ES result, that for CMJ was very small and for SJ was null. These findings indicate that the general warm-up was better for improving performance in the subsequent power activity compared to the specific warm-up. Plyometric exercises are performed during a warm-up aiming to promote PAPE (Krzysztofik & Wilk, 2020; Tobin & Delahunt, 2014). However, this indicates a possible coexistence between PAPE, fatigue, and motor pattern interference (preservation) (Blazevich & Babault, 2019), that could be influenced by a dose of PCE. Therefore, a possible explanation for the results found could be the high volume of plyometric exercises performed. Although a plyometric warm-up protocol with a similar volume (3 plyometric exercises; 2 x 8 repetitions; total volume of 48 jumps) increased leg stiffness and running economy of healthy adult recreational athletes (Wei et al., 2020), this dose of PCE could be high for the sample included in the present study (physically active healthy men). In other studies with endurance runners (~6 drop jumps (Blagrove et al., 2019) and with adult professional soccer players (2 repetitions of a maximal vertical jump (Brink et al., 2022), lower training loads applied during the warm-up were sufficient to improve running economy (Blagrove et al., 2019) and vertical jump performance (Brink et al., 2022). Therefore, future studies should be performed to investigate if different doses of plyometric exercises may promote a higher positive effect on performance in subsequent physical tests in physically active healthy adult males.

The recovery time given (10 min) between the warm-up and the physical tests could also justify the lower effect reported for the specific warm-up. Although PAPE has a time course that can last from 6 to 15 minutes (Blazevich & Babault, 2019), in a recent study the improvement in maximal vertical jump was shown up to 2 minutes after a warm-up protocol using maximal vertical jumps and multiple vertical jump series (Brink et al., 2022). Other studies with soccer players (Guerra et al., 2020), and with professional rugby players (Tobin & Delahunt, 2014) showed increased CMJ performance 1, 3, and 5 minutes post warm-up with plyometric exercises. The idea that the PAPE effect may be reported earlier after plyometric exercises was demonstrated by Barreto et al., (2023), who showed that although performance in the CMJ increased up to 9-min after the plyometric exercises, higher results were shown at 1-min. Further studies that include physical performance tests from 0 to 15 min after the PCE are necessary in order to understand the time course of PAPE after plyometric exercises.

The lack of difference between the warm-up strategies for time to run 1,000 meters suggests that both protocols could be used if the aim is to change performance in this running exercise. The improvement in performance in long-term and intermediate maximal exercises is more widely reported after a general warm-up (Bishop, 2003a; Grodjinovsky & Magel, 1970), especially when associated with increased baseline oxygen consumption (Bishop, 2003a). Although the oxygen consumption was not reported in the present study, we believe that the time (6 minutes) and intensity (exertion of 2-3 on 0-10 Borg scale), could be appropriate to improve baseline oxygen consumption (Bishop, 2003a). The effect of plyometric exercise performed during the warm-up to improve running performance parameters has also been reported previously (Blagrove et al., 2019; Boullosa et al., 2018, 2020; Low et al., 2019; Wei et al., 2020). For example, Blagrove et al., (2019) found that 6 drop jumps were sufficient to improve the running economy of junior endurance runners. Boullosa et al., (2020), showed improvement in performance time and pacing in a 1,000 meter running test when 5 drop jumps were added to a standard warm-up of elite endurance runners. Unfortunately, a control group was not included in the present study, making it impossible to state whether the warm-ups improved performance in the running exercise. This can be considered a limitation of the present study and future studies should investigate this possibility.

Conclusions

It was concluded that for physically active healthy adult males, both general and specific (using plyometric exercises) warm-up protocols improved performance in subsequent power tests, with pronounced effects reported for the general warm-up. Furthermore, there were no differences between general and specific warm-ups on time to perform a subsequent 1,000 meter running exercise. Based on the results found, coaches and physical trainers may consider including both the GW and PW warm-up protocols performed in the present study to enhance subsequent performance in activities that require lower limb power. PW may be considered when the subsequent exercise involves the stretch-shortening cycle, and GW should be preferred for power exercises with emphasis on the concentric phase.

Conflicts of interest - The authors do not have any conflicts of interest to declare.

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