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Effects of general, specific and combined warm-up on explosive muscular performance

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ABSTRACT: The purpose of this study was to compare the acute effects of general, specific and combined warm-up (WU) on explosive performance. Healthy male (n=10) subjects participated in six WU protocols in a crossover randomized study design. Protocols were: passive rest (PR; 15 min of passive rest), running (Run; 5 min of running at 70% of maximum heart rate), stretching (STR; 5 min of static stretching exercise), jumping [Jump; 5 min of jumping exercises – 3x8 countermovement jumps (CMJ) and 3x8 drop jumps from 60 cm (DJ60)], and combined (COM; protocols Run + STR + Jump combined). Immediately before and after each WU, subjects were assessed for explosive concentric-only (i.e. squat jump – SJ), slow stretch-shortening cycle (i.e. CMJ), fast stretch-shortening cycle (i.e. DJ60) and contact time (CT) muscle performance. PR significantly reduced SJ performance ($p = 0.007$). Run increased SJ ($p = 0.0001$) and CMJ ($p = 0.002$). STR increased CMJ ($p = 0.048$). Specific WU (i.e. Jump) increased SJ ($p = 0.001$), CMJ ($p = 0.028$) and DJ60 ($p = 0.006$) performance. COM increased CMJ performance ($p = 0.006$). Jump was superior in SJ performance vs. PR ($p = 0.001$). Jump reduced ($p = 0.03$) CT in DJ60. In conclusion, general, specific and combined WU increase slow stretch-shortening cycle (SSC) muscle performance, but only specific WU increases fast SSC muscle performance. Therefore, to increase fast SSC performance, specific fast SSC muscle actions must be included during the WU.

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INTRODUCTION

Warm-up (WU) refers to muscle actions performed before a higher muscle demand, usually before high-intensity competitive or recreational events take place [1,2], traditionally involving general and specific WU exercise [3]. While general WU usually involves a relatively low-intensity aerobic component (e.g. submaximal running) and stretching exercises [4], specific WU involves specific-skill exercises [4]. One of the more important aims of WU is to increase performance [5] through increasing muscle temperature, reducing the muscle's viscous resistance (i.e. smoother contraction), or increasing the speed of nerve transmission [6].

Commonly, WU protocols tend to reflect the experience of individual coaches or athletes [1], and the effects of the WU itself have been poorly studied [7,8]. In this regard, the American College of Sport Medicine (ACSM) recently indicated that more controlled studies are needed to substantiate the effectiveness of WU protocols [9]. Interestingly, controlled studies regarding the effects of WU on explosive performance are particularly scarce, maybe due to the unwillingness of voluntary subjects to complete a maximal effort without WU (i.e. control condition). Among the scarce studies investigating the effect of WU protocols on explosive muscular performance, conflicting results have arisen. Although some studies have shown an increase in explosive performance after general [10] or specific [11,12] or combined general and specific WU [3], others have not shown a significant effect [10,13,14]. Therefore, the purpose of this study was to clarify the acute effects of general, specific and combined WU on explosive muscular performance.

MATERIALS AND METHODS

Participants. Ten healthy subjects were recruited for this study (height: 1.74 ± 0.02 m; body mass: 71.3 ± 0.42 kg; age: 20.6 ± 0.64 years). Body mass and height were measured using a calibrated balance scale (HA-621 Tanita, Illinois, USA) and a stadiometer (But-

terfly, Shanghai, China), respectively. All subjects were students of physical education, with no history of injury in the previous 6 months. Before the study, all subjects performed two practice sessions in which the WU and testing exercises were executed. Prior to the testing sessions, all subjects were instructed to avoid intense physical activity and not drink coffee or any energetic beverages at least 24 h before measurements. During the study period, subjects were asked to maintain their normal daily routines. The study was conducted in accordance with the Declaration of Helsinki and approved by the Ethics Committee of the Department of Physical Activity Sciences, University of Los Lagos. Subjects were carefully informed about the experiment procedures, as well as the possible risks and benefits associated with participation in the study, and an appropriate signed informed consent form was obtained pursuant to law before any of the tests were performed. No subject withdrew from this study as a consequence of injury or other adverse experiences.

Study Design

The study was a randomized, single-blind crossover trial. All subjects participated in the control and experimental interventions. Other studies have found that this is a good design when using a small sample size [15], reducing the chance of a learning effect during application of tests. We compared the acute effects of 5 different WU protocols (i.e. passive rest, running, stretching, jumping and combined) on explosive muscle performance.

Procedures

All study procedures took place in a wooden gymnasium, between 09:00 AM and 12:00 PM, with the environmental temperature between 13 and 18°C. After arrival at the gymnasium and before the commencement of any WU protocol, subjects passively rested until reaching a heart rate of 60-70 beats per minute. Based on previous research [16], five WU protocols were performed in random order, during non consecutive days (Figure 1).

Warm-up Protocols

Passive Rest Protocol (PR). During PR, subjects maintained a comfortable sitting position for 15 min.

Jumping Protocol (Jump). Subjects performed 3 sets of 8 countermovement jumps (CMJ), and 3 sets of 8 drop jumps (DJ) from 60 cm (DJ60), with 20 s and 30 s of passive rest between sets and exercises, respectively. All jumps were performed with maximum effort. The entire protocol lasted 5 min.

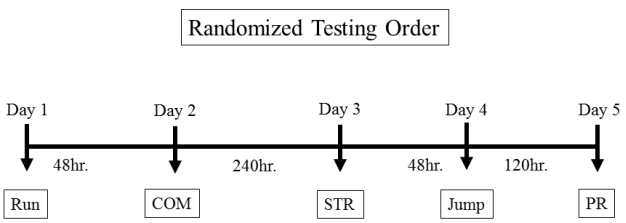

FIG. 1. Randomized testing order.
PR: passive rest; Run: running; STR: stretching; Jump: jumping; COM: combined (Run+STR+Jump).

Running Protocol (Run). Subjects ran for 5 min [17] at a velocity equivalent to 70% of their predicted maximum heart rate (HR; 220 – age) on an indoor track. The measurement of HR was conducted with a HR digital monitor (RS800CX, Polar electro, Finland).

Stretching Protocol (STR). Subjects completed 6 static stretching (SS) exercises with an intensity equivalent to 5-6 on the 10-point Borg subjective perception scale (10 points). One set of 20 s was completed per exercise, with 15 s of passive rest between them. The SS exercises were intended for specific muscle groups (i.e. hamstring, quadriceps, gastrocnemius, soleus, adductor, psoas iliac), and were performed according to Anderson's descriptions [18,19] (Table 1). The entire stretching WU protocol lasted approximately 5 min.

TABLE I. Static stretching exercises

Exercises	Description
Hamstring Stretching	Subject sits with trunk as vertical as possible. One leg is extended and the other flexed with the sole of the foot in contact with the inner thigh of the extended leg. Subject leans forward and touches toes of the extended leg with both hands. The same procedure is carried out with the opposite leg [18].
Quadriceps Stretching	Sitting on the floor, subject bends one leg and rests it to his side. The foot must not deviate out to the side (it must be extended behind subject). Then, subject leans back slowly to stretch the quadriceps. The same procedure is carried out with the opposite leg [18].
Gastrocnemius Stretching	For gastrocnemius stretching, subject stands a little way from a solid support and leans on it with his forearms; his head rests on his hands. Subject bends one knee and places his foot on the ground in front of him, leaving the other leg straight behind him. Slowly, subject moves his hips forward until he feels the stretch on the gastrocnemius on his straight leg. Subject keeps the heel of the foot of the straight leg on the ground and his toes pointed straight ahead. Then, for soleus stretching, the subject bends the knee back, keeping the foot flat. The same procedure is carried out with the opposite leg [18].
Adductor Stretching (butterfly stretch)	In a sitting position, subject puts the soles of his feet together. With his hands around his feet, subject pulls himself forward. Subject keeps his elbows on the outside of his legs to give them stability in the stretch. Subject initiates the movement forward from his hip, not with his head and upper back [18].
Psoas Iliac Stretching (lunge stretch)	Subject moves his leg forward until the knee of the forward leg is directly over the ankle. His other knee should be resting on the floor. Subject leans forward without changing the position of the knees on the floor or the forward foot [19].

Combined Protocol (COM). Subjects combined Run + STR + Jump protocols, with 30 s of passive rest between them. The COM lasted approximately 15 min.

Before and after each WU protocol, subjects were evaluated in random order on the squat jump (SJ), CMJ, and DJ60 test.

Performance Evaluation

DJ60. Subjects performed DJs from a 60-cm high platform onto an electronic contact mat system (AXON JUMP 4.0, Bioengineering Sports, Argentina 2011) [20]. The subjects were instructed to place their hands on their hips and step off the platform with the leading leg straight to avoid any initial upward propulsion, ensuring a drop height of 60 cm. They were instructed to jump for maximal height and minimal contact time, in order to maximize jump reactive strength [21]. The subjects were again instructed to leave the platform with knees and ankles fully extended and to land in a similarly extended position to ensure the validity of the test. Four basic techniques were stressed: (i) correct posture (i.e., spine erect, shoulders back) and body alignment (e.g., chest over knees) throughout the jump; (ii) jumping straight up with no excessive side-to-side or forward-backward movement; (iii) instant recoil for the concentric part of the jump. Phrases such as "on your toes", "straight as a stick", "light as a feather", and "recoil like a spring" were used as verbal and visualization cues during the DJs. The instructions given to the subjects were "jump as high as you can, with minimum ground contact time". Three maximal repetitions were executed, with 30 s between repetitions. The best performance trial was used for the subsequent statistical analysis. The reactive strength ($cm \cdot ms^{-1}$) and contact time (ms) of the best trial were evaluated. Previous research from our laboratory shows high reliability for this test protocol [22].

Countermovement Jump. A CMJ was used in order to assess maximal jump height performance requiring slow stretch shortening cycle (SSC) action. The CMJ test was performed using an electronic contact mat system (AXON JUMP 4.0, Bioengineering Sports, Argentina 2011) [20]. Jump height was determined using an acknowledged flight-time calculation [23]. During the CMJ, the subject was instructed to rest his hands on his hips, with feet and shoulders wide apart; subjects performed a downward movement, with no restriction imposed over the knee angle achieved [24], followed by a maximum effort vertical jump. All subjects were instructed to land in an upright position and to bend the knees following landing. Three maximal trials were completed, with 30 s of passive rest between them, and the best performance trial was used for the subsequent statistical analysis.

Squat Jump. A SJ was used to assess maximal concentric-only explosive strength performance. The SJ test was performed using an electronic contact mat system (AXON JUMP 4.0, Bioengineering Sports, Argentina 2011) [20]. Jump height was determined using an acknowledged flight-time calculation [23]. During the SJ, the subject was instructed to rest his hands on his hips, with feet shoulder width apart, adopt a standardized flexed knee position of approximately 90º (determined with a goniometer) for 3 s [25], and follow with a maximum effort vertical jump. All subjects were instructed to land in an upright position and to bend the knees following landing. Three maximal trials were completed, with 30 s of passive rest between them, and the best performance trial was used for the subsequent statistical analysis.

A rest period of 2 min was applied between tests.

Statistical Analysis

All data are expressed as mean ± standard deviation (SD). Normality was determined with the Shapiro-Wilk test. A 2-way ANOVA for repeated measures [5 WU protocols × 2 times (i.e. before and after WU protocols)] followed by a Bonferroni two-tailed least significant difference post hoc test was used to test the null hypothesis. The software used was Statistical Package for the Social Sciences (SPSS, Ins. Chicago, IL), version 19.0. The alpha level for significance was set at $p < 0.05$.

RESULTS

SJ performance. No significant differences between WU conditions were observed before application of WU protocols. Only Run ($p = 0.0001$) and Jump ($p = 0.001$) induced a significant increase in SJ performance, while PR induced a significant reduction ($p = 0.007$). After application of WU protocols, a significantly higher SJ performance was observed in Jump vs. PR ($p = 0.001$) (Figure 2).

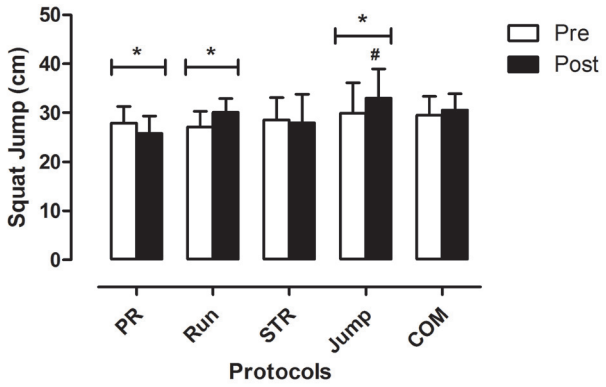

FIG. 2. Acute effects of different warm-up conditions on squat jump performance.
PR: passive rest; Run: running; STR: stretching; Jump: jumping; COM: combined (Run+STR+Jump). Pre: before warm-up; Post: after warm-up. Data are presented as mean ± SD. *: denotes statistically significant ($p<0.05$) difference between before and after the warm-up period; #: denotes statistically significant ($p<0.05$) difference vs. PR group after the warm-up period.

CMJ performance. No significant differences between WU conditions were observed before application of WU protocols. After Run ($p = 0.002$), STR ($p = 0.048$), Jump ($p = 0.028$) and COM ($p = 0.006$) a significant increase in CMJ performance was observed. No significant differences between WU conditions were observed after application of WU protocols (Figure 3).

DJ60 performance. No significant differences between WU conditions were observed before application of WU protocols. A significant ($p = 0.006$) increase in reactive strength (Figure 4) and a significant ($p = 0.03$) reduction in contact time (Figure 5) were observed after Jump protocol. After application of WU protocols, a significantly ($p = 0.031$) superior reactive strength was observed in COM vs. PR (Figure 4).

DISCUSSION

The purpose of this study was to determine the acute effects of specific WU, general WU, and their combination, on explosive jump-strength performance. Our main findings showed that general WU (i.e. running, stretching), specific WU (i.e. jumping) and combined (i.e. running, stretching and jumping) WU induced a significant increase in explosive concentric-only and slow SSC muscle performance, but only specific WU induces a significant increase in fast SSC muscle performance, and this improvement in fast SSC muscle performance was achieved with a very low volume of muscle activity (i.e. less than 48 s). These results are similar to previous studies where an increase in explosive concentric-only (i.e. SJ) and slow SSC (i.e. CMJ) muscle performance was observed after general (i.e. running, stretching) and specific (i.e. jumping) WU [11,14,17]. However, not all studies agree [14,26]. Differences between our results and previous investigations may be related to the degree of fatigue during WU. For example, during our specific (i.e. Jump) WU protocol, although we used high intensity, a low volume of muscle activity was required (i.e. less than 48 s), maximizing the probability of inducing a post-activation potentiation effect [27] and reducing the chances of fatigue [14].

The improvement after general and specific WU activities can be explained by an increased muscle temperature, favourably affecting muscle performance by reducing the muscle's viscous resistance, which may induce a smoother contraction [6], an increased speed of rate-limiting oxidative reaction and/or increased oxygen delivery to muscles [6,27,28] through greater vasodilatation [6]. This is in addition to an increase in nerve transmission velocity, which may result in increased muscle contraction speed and reduced reaction time [6]. Interestingly, only specific (i.e. Jump) WU induced a significant increase in fast SSC muscle performance (i.e. DJ60 reactive strength), which was achieved by means of a significant reduction in contact time. This may be explained by the fact that only high-intensity muscle activity (i.e. DJ) induced a post-activation potentiation effect, improving the muscles' contractile performance in subsequent high-intensity fast SSC muscle actions [27]. This can be

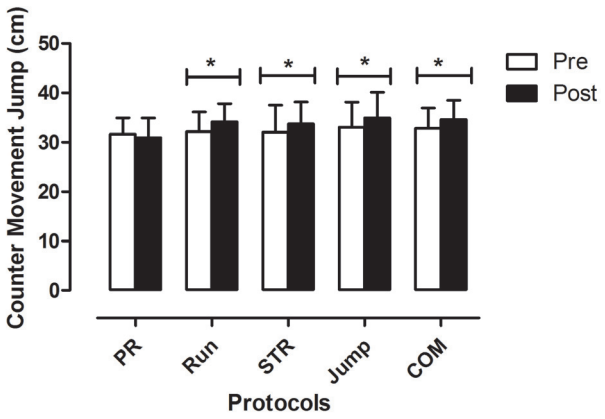

FIG. 3. Acute effects of different warm-up conditions on countermovement jump performance.
PR: passive rest; Run: running; STR: stretching; Jump: jumping; COM: combined (Run+STR+Jump). Pre: before warm-up; Post: after warm-up. Data are presented as mean ± SD. *: denotes statistically significant ($p<0.05$) difference between before and after the warm-up period.

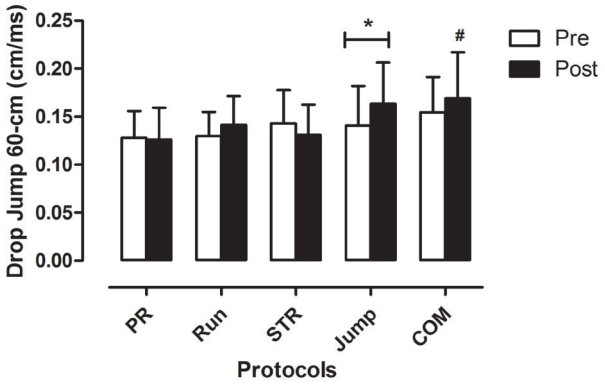

FIG. 4. Acute effects of different warm-up conditions on drop jump performance.
PR: passive rest; Run: running; STR: stretching; Jump: jumping; COM: combined (Run+STR+Jump). Pre: before warm-up; Post: after warm-up. Data are presented as mean ± SD. *: denotes statistically significant ($p<0.05$) difference between before and after the warm-up period; #: denotes statistically significant ($p<0.05$) difference vs. PR group after the warm-up period.

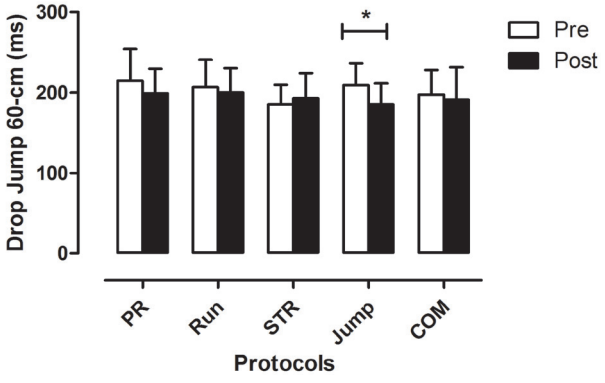

FIG. 5. Acute effects of different warm-up conditions on contact time performance.
PR: passive rest; Run: running; STR: stretching; Jump: jumping; COM: combined (Run+STR+Jump). Pre: before warm-up; Post: after warm-up. Data are presented as mean ± SD. *: denotes statistically significant ($p<0.05$) difference between before and after the warm-up period.

attributed to elevation of Ca2+ in the cytosol of musculoskeletal cells [29]. Also of interest, a significant difference in SJ performance vs. PR was observed only after Jump WU, suggesting that specific WU may add not only to fast SSC muscle performance, but also to concentric-only explosive muscle activity. These results have important practical relevance, since many competitive sports require a combination of fast and slow SSC muscle actions to succeed.

Interestingly, in 1998 the ACSM [30] recommended the application of stretching exercises during WU protocols, but in 2011 [9] the ACSM changed their position, indicating that more controlled studies are needed. Our results show that the STR group significantly increased CMJ performance, similarly as in previous research [31]. Because we use a short duration (i.e. 20 s) of stretching per muscle group and a low stretch intensity (i.e. avoiding the point of discomfort), and considering that a CMJ involves a slower velocity of eccentric contraction and more prolonged SSC (i.e. vs. DJ60), these factors may help explain the CMJ performance increase [[32]. However, considering that static stretching exercise may reduce muscle stiffness [8], which may negatively affect SSC muscle performance [2], it is not surprising to find several reports where vertical jump performance and other powerful muscle actions were reduced after stretching exercises [5,7,20]. Moreover, our results show that the COM protocol [where stretching exercises were added to those that demonstrated a significant and positive effect on fast SSC muscle performance (i.e. jumping) and concentric-only explosive strength (i.e. jumping, running)] did not add to the explosive performance of subjects, suggesting that a negative interference effect may have occurred with static stretching in relation to fast SSC muscle performance and concentric-only explosive performance. Therefore, although we observed a significant effect of static stretching exercises on CMJ performance, we suggest that athletes apply other types of muscular activity (i.e. jumping, running) during WU before short-term powerful muscular performance activities, especially before those requiring fast SSC or concentric-only powerful muscle actions.

A novel finding in our study was the "limited" performance enhancement observed with COM, where only CMJ performance was improved, as compared to the CMJ and SJ improvement observed after Run and the CMJ, SJ and DJ60 improvement observed after Jump. In addition, the duration of COM was three times higher vs. Run, STR and Jump, resulting in a reduced efficiency in time investment with the former WU condition. Contrary to previous reports [3], the combination of general and specific WU activities did not result in significant superior explosive performance compared to the application of isolated general or specific WU. This may be related to the fact that during COM, static stretching exercises were added, which (although it may positively impact CMJ performance, as our results show) may negatively impact rapid SSC and concentric-only powerful muscle performance [1]. Alternatively, subjects may have been fatigued after the COM protocol [14], which took three times as long to complete in comparison with the other WU protocols, therefore reducing the potentially positive effect of combined general and specific WU muscle actions on explosive performance.

As expected, PR rest protocols did not induce a positive effect on explosive performance. In fact, after the PR protocol a significant reduction (-8%) in SJ performance was observed. Likely, 15 min of passive rest may have reduced muscle temperature, altering muscle spindle function [6], hence altering muscle contraction behaviour [33] and potentially limiting short-term maximal effort muscle performance.

CONCLUSIONS

General, specific and combined WU increase slow SSC muscle performance, but only specific WU increases fast SSC performance. Therefore, to increase fast SSC performance (and also slow SSC performance), we recommend that specific low-volume, high-intensity fast SSC muscle actions be included during WU before short-term maximal performance events. However, care must be taken to avoid undue combination of specific fast SSC muscle actions during WU with other exercises that may potentially reduce its positive effects (e.g. static stretching) on fast SSC performance.

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