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Research article

Effects of High-Intensity Warm-Up on 5000-Meter Performance Time in Trained Long-Distance Runners

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Abstract
Warm-up protocols with high intensities before continuous running provide potential benefits for middle-distance runners. Nevertheless, the effect of high-intensity warm-ups on long-distance runners remains unclear. The purpose of this study was to verify the effect of a high-intensity warm-up protocol on 5000 m performance in trained runners. Thirteen male runners (34 ± 10 years, 62 ± 6 kg, 62.7 ± 5.5 ml/kg/min) performed two 5000 m time trials, preceded by two different warm-ups. One high-intensity warm up (HIWU: 1x 500 m (70% of the running intensity) + 3x 250 m (100% of the running intensity) and one low-intensity warm up (LIWU: 1x 500 m (70% of the running intensity) + 3x 250 m (70% of the running intensity)), where the running intensities were calculated using the results obtained in the Cooper test. Physiological and metabolic responses, and endurance running performance parameters, were evaluated by the Counter Movement Jump (CMJ), running rating of perceived exertion (RPE), blood lactate concentration (BLa), and performance running. Total time for the 5000 m was lower using HIWU when compared to LIWU (1141.4 ± 110.4 s vs. 1147.8 ± 111.0 s; $p = 0.03$; Hedges' g = 0.66). The HIWU warm-up led to an improvement in pacing strategy during the time trial. After warm-up protocols, the performance on the CMJ was improved only when applying HIWU ($p = 0.008$). Post warm-up BLa was significantly higher for HIWU vs. LIWU (3.5 ± 1.0 mmol·L^{-1} vs. 2.3 ± 1.0 mmol·L^{-1}; $p = 0.02$), with similar behavior for the RPE ($p = 0.002$), internal load of the session ($p = 0.03$). The study showed that a high-intensity warm-up protocol can improve performance in the 5000 m in trained endurance runners.

Key words: Running, warm-up exercise, athletic performance, exercise tolerance, endurance exercise.

Introduction

The warm-up is considered an essential precursor for training sessions and sports competitions (Silva et al., 2018). It impacts on the articular, muscular and psychological preparedness of athletes (McGowan et al., 2015; Emery et al., 2022). Furthermore, warm-ups contribute to improving sports performance by promoting the acceleration of metabolic reactions, increasing muscle temperature, heart rate, blood flow and oxygen transport to peripheral muscles, post-activation potentiation, nerve conduction rates, and joint lubrication (Bishop, 2003; García-Pinillos et al., 2020).

For long-distance running, traditional warm-up routines use a general or specific approach, depending on the length of the period, short or long (van den Tillaar et al., 2017). Another important feature in the protocols is related to the use of low-intensity during the warm-up (García-Pinillos et al., 2019). Different warm-up protocols with high intensities before continuous running may provide more significant benefits. Both increased performance in 800 m (Ingham et al., 2013) and 1600 m (Paris et al., 2021) runs and increased total time during the exhaustion test (González-Mohíno et al., 2018) have been observed. In addition, some researchers have adopted a long transition period (the period between the conclusion of the warm-up and the beginning of the run), lasting between 18 and 20 minutes, aiming at ecological validity and optimal recovery of runners (Ingham et al., 2013; González-Mohíno et al., 2018; Paris et al., 2021).

High-intensity warm-ups are associated with modifications in the hematosis processes (e.g., the release of oxygen to the active musculature and removal of carbon dioxide) and metabolic reactions (e.g., a degree of lactic acidosis (≤ 3 mmol. L^{-1}) and adenosine triphosphate turnover). The reduction of the slow component (responsible for lower muscle efficiency (Caritá et al., 2014)), a higher basal bioavailability of oxygen (O_2) (Burnley et al., 2011; Sousa et al., 2014), an increase in muscle glycogen availability, and increased strength rate development have been highlighted (Bishop, 2003; McGowan et al., 2015). These mechanisms can positively influence performance in medium (from 800 - 3000 m) and long-distance (≥ 5000 m) running, especially in the final stages of the course (where higher speeds are commonly employed) (Abbiss and Laursen, 2008).

Some running events in athletics are characterized by periods of sustained high-intensity bouts that last longer than two minutes (e.g., 1500 m, 3000 m, 5000 m, among other races) executed through pacing strategies. (Abbiss and Laursen, 2008; Cuk et al., 2019). Analysis of the results of 5000m world finalists has registered U-paced profiles with faster beginning and ending 1000 m segments (Abbiss and Laursen, 2008; Cuk et al., 2019). Thus, the runner increased the running speed to complete the

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distance (Casado et al., 2021a; Menting et al., 2022). Specifically for athletes competing in 5000 m races, characterized by their prerequisite of aerobic capacity and significant contribution of anaerobic capacity (Tharp et al., 1997; Baumann et al., 2012), runners tended to adopt a U-shaped pacing strategy, employing a greater running speed in the initial and final kilometers of the race (Girard et al., 2013).

Although a low-intensity warm-up has not shown any potentiating effects on running performance (Bishop et al., 2001; Zourdos et al., 2017; Alves et al., 2019), warm-up protocols for 5000 m runners do not include high-intensity loads for fear of the early onset of voluntary motor fatigue, promoting a decrease in performance (García-Pinillos et al., 2019). In contrast, maximal (at an estimated 800 m race pace) and supramaximal loads (105% of maximal O_2 consumption (VO_2max)) have been related to an improvement in performance in middle-distance running (Ingham et al., 2013; González-Mohíno et al., 2018; Paris et al., 2021).

The purpose of this study was to verify the effect of a high-intensity warm-up protocol on 5000 m performance in trained runners. We hypothesized that the running performance would improve with a high-intensity warm-up compared to a low-intensity warm-up.

Methods

Design and participants

This is a randomized crossover intervention study that recruited male runners from the city of Aracaju, Sergipe – Brazil. The recruitment of the runners occurred through invitations sent by coaches and sports consultants. Eligibility criteria included: (1) age ≥ 18 years; (2) pace ≤ 4:28 min/km in the 5000 m; (3) weekly frequency of three to five running sessions; (4) absence of osteoarticular and muscular lesions in the last six months that prevented running; (5) not being enrolled in another exercise program during the study; and (6) a minimum of one year of experience in running 5000 m.

Initially, 19 runners met the criteria for participation, but six participants were excluded from data analysis by the following criteria: injury during the familiarization session (n = 1), the manifestation of upper respiratory tract infection during the evaluation period (n = 1), absence on a collection day (n = 3) and starting another sport activity during collection (n = 1). Thus, the final sample comprised 13 male runners aged 19-52.

After receiving detailed information about the objectives and procedures of the study, each participant signed an informed consent form. This study complied with the Helsinki Declaration and was approved by the Ethics Committee on Human Research of the Federal University of Sergipe (CAAE 43328921.3.0000.5546 / Opinion Number: 4.788.788).

Experimental design

The participants visited the Department of Physical Education at the Federal University of Sergipe (DEF-UFS) three times, separated by 72 hours of rest and no physical exercise. The first visit included anthropometric evaluations (body mass and height), estimation of VO_2max (Cooper test) (Cooper, 1968), measurement of explosive strength capacity via Counter Movement Jump (CMJ) (Blagrove et al., 2019), and familiarization with the warm-up protocols. The two following visits were made to execute at random one of the warm-up protocols (high-intensity or low-intensity) and perform the 5000 m time trial (Figure 1A).

Randomization was performed using Excel 2019 software, randomly allocating participants to two warm-up protocols, high-intensity (HIWU) and low-intensity

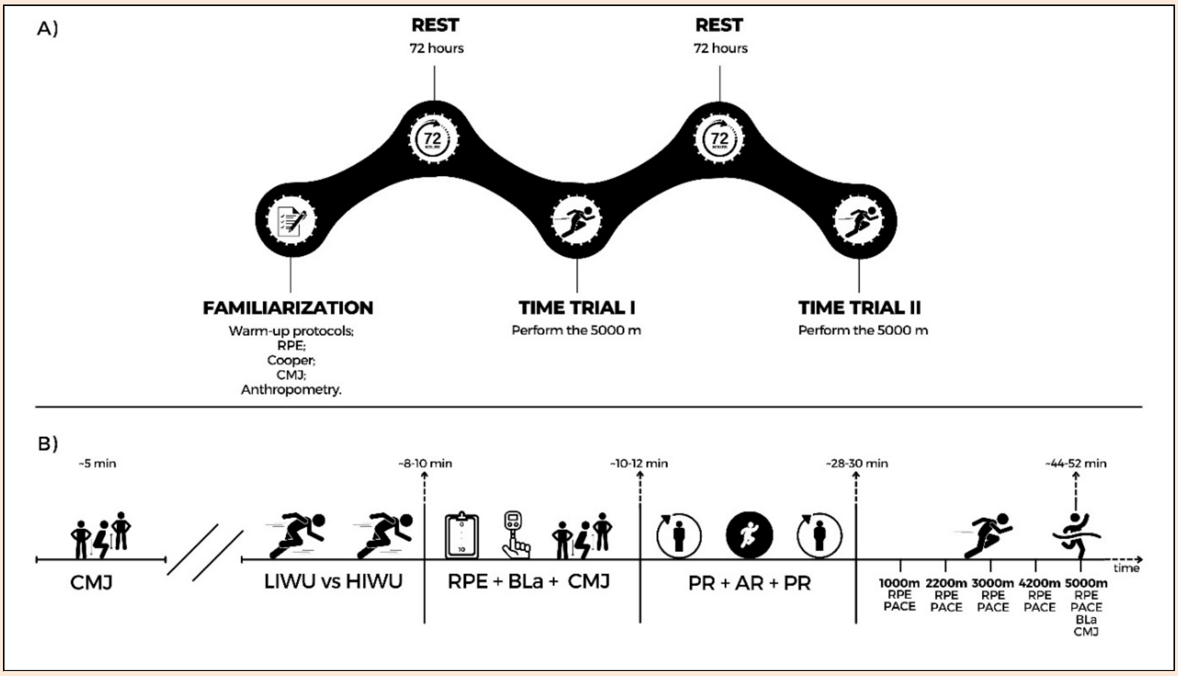

Figure 1. Study design. A) Experimental design. B) Experimental design of the time trial. LIWU = Low-Intensity Warm-Up; HIWU = High-Intensity Warm-Up; RPE = Rating of Perception Effort; BLa = Blood Lactate Concentration; CMJ = Counter Movement Jump; PR = Passive Recovery; AR = Active Recovery; PACE = distance/time.

(LIWU), both lasting between 8 - 10 minutes, followed by an 18 min transition period. The transition period consisted of 10 min of passive recovery (PR) (standing and silent), followed by 5 min of active recovery (AR) composed of 5 running drills (Azevedo et al., 2015; Alves et al., 2019) (low skipping, high skipping, single-leg hop, anfersen, and kicks) performed in two cycles of 15 s intersected with 15 s of rest, and finalized with 3 min of PR. After these steps, the 5000 m time trial was started. During the protocol, the following variables were collected: the rating of perceived exertion (RPE) was recorded at the post warm-up, at four splits of the time trial (1000 m, 2200 m, 3000 m, 4200 m), and immediately after the time trial. The blood lactate concentration (BLa) was collected immediately after the warm-up and time trial. CMJ was measured 5 minutes before starting the warm-up protocols, after the warm-up and immediately after the trial. The average running pace (PACE) was recorded during the entire time trial run (Figure 1B).

Warm-up protocols

A 500 m run (70% of the intensity obtained in the Cooper test) was performed as the standard warm-up for both LIWU and HIWU, followed by the experimental condition 3× 250 m (100% of the intensity obtained in the Cooper test) - HIWU or control condition 3× 250 m (70% of the intensity obtained in the Cooper test) - LIWU. In both protocols, all runs were interspersed with two minutes of PR. The intensities of the runs (70 and 100%) were calculated by the distance achieved in the Cooper test (Cooper, 1968), and the time to complete the runs (500 and 250 m) in seconds, based on the mathematical model described below:

500m and 250 m (70%): $$Time = \left(\frac{720 \times m}{d}\right) \times \frac{1}{0.7}$$

250 m (100%): $$Time = \left(\frac{720 \times m}{d}\right)$$

where 720 is the 12-minute Cooper test converted to seconds; m is the warm-up distance (250 or 500 m); 0.7 is 70% intensity; and d is the distance the athlete completed in the Cooper test.

Continuous running test - 5000 m time trial

Immediately after the transition period, the 5000 m time trial was performed individually on the official athletic track of DEF-UFS. During the time trial, the participants were encouraged through clapping and words of encouragement. The participants were given information about the number of laps but not about the splits or final time. The splits (P1 = 200 m, P2 = 600 m, P3 = 1000 m, P4 = 1400 m, P5 = 1800 m, P6 = 2200 m, P7 = 2600 m, P8 = 3000 m, P9 = 3400 m, P10 = 3800 m, P11 = 4200 m, P12 = 4600 m, and P13 = 5000 m) and total time were monitored with a digital chronometer (Vollo Sports, model VL515, São Paulo, Brazil).

Blood lactate concentration

The BLa was collected by pricking the index finger of the right hand with a generic automatic lancet (GTECH, Barueri, São Paulo, Brazil), to get a drop of blood sufficient to fill the space on a reagent strip of the Accutrend "Accutrend Plus" lactate analyzer (Boehringer Mannheim, Indianapolis, IN).

Evaluation of the explosive strength capacity of lower limbs

For the countermovement jump (CMJ) evaluation, The subject started in a standing upright position with his feet on a mat and with his hands on his hips, followed by a downward movement flexing his knees to approximately 90° to then immediately jump as high as possible. (Blagrove et al., 2019). The test was performed using the Chronojump-Bosco (Barcelona, Spain) jumping platform connected to computer software. Each athlete had three attempts separated by 10 s. The highest jump was used for further analyses.

Rating of perceived exertion and internal load of the training session

The CR-10 (Borg, 1998) perceived exertion scale was used to assess RPE. To calculate the internal load of the session (ILS), the proposal by Foster (Foster, 1998) was used (value of RPE obtained after the 5000 m TT test or warm-up multiplied by its respective duration in minutes). The participants were already familiar with RPE, and during the familiarization visit were trained to shout out the RPE number at five time moments (P3, P6, P8, P11, and P13).

Anthropometric evaluation

The body mass and height of the volunteers were evaluated for sample characterization. Body mass and height were measured using a Toledo® analog scale with an attached stadiometer with a 0.1 kg and 0.1 cm precision scale, respectively.

Statistical analysis

Continuous variables were described as mean ± standard deviation. Normality and homogeneity of variances were checked by the Shapiro-Wilk and Levene tests, respectively. T-test was used for dependent samples to compare the final time in the time trial, RPE, and ILS in the post warm-up. Two-way repeated measures analysis (ANOVA) was used to identify the effect of time and condition on average speeds by splits, CMJ, BLa, and RPE, followed by Bonferroni post hoc comparisons. The Hedges' g was verified as a measure of effect size for each pairwise comparison and interpreted as trivial (<0.20), small (0.20 - 0.49), moderate (0.50 - 0.79), and large > 0.80 (Cohen, 1992). Statistical analyses were performed using SPSS software version 25.0 (IBM Corp., Chicago, IL, USA) with statistical significance established at p-value < 0.05. Graphical representations were performed in GraphPad Prism software version 9.0 (GRAPH PAD Software Inc, California, USA).

Results

Table 1 shows the participants characterization. The participants presented a mean age of 34±10 years, with approximately 9 years of practice in middle-long distance running, and a mean distance of 3311 m in the Cooper test.

Performance in the 5000 m time trial was statistically superior in the HIWU condition compared to LIWU (1141.4 ± 110.4 s vs. 1147.8 ± 111.0 s; $p = 0.03$; Hedges' g = 0.66) (Figure 2A). Individual analysis indicated better performance in the HIWU condition for 10 of the 13 participants (Figure 2B).

Mean running speeds over the 13 splits indicated that runners tended to be faster under the HIWU condition relative to LIWU in 10 of the 13 splits (Figure 3A), specifically in splits P2, P3, and P10, with reductions in time of 1.8 s, 1.7 s, and 1.6 s respectively (Figure 3B). The results for the pacing strategy indicated that the participants under the HIWU condition showed statistically superior initial average running speed in P1 to P2 (up to 600 m) compared to the P3 to P12 interval (1000-4600m) of the 5000 m.

We observed an increase in CMJ height after warm-up only for participants under the HIWU condition compared to the initial moment (24.9 ± 5.7 cm vs. 29.0 ± 5.6 cm; $p = 0.008$). In the LIWU condition, there was an increase in CMJ height only in the post time trial moment when compared to the initial moment (24.2 ± 4.6 cm vs. 28.5 ± 3.7 cm; $p = 0.01$) (Figure 4).

For BLa, a significant increase was found when comparing the post warm-up vs. post 5000 m time trial (HIWU: 3.5 ± 1.0 $mmol \cdot L^{-1}$ vs. 13.7 ± 5.1 $mmol \cdot L^{-1}$; $p < 0.001$; LIWU: 2.3 ± 1.0 $mmol \cdot L^{-1}$ vs. 13.0 ± 4.8 $mmol \cdot L^{-1}$; $p < 0.001$). When comparing the two conditions, we identified a significant difference only in the post warm-up comparison ($p = 0.02$) (Figure 5).

In addition, in the post warm-up, a significant difference was found in RPE ($p = 0.002$) and ILS ($p = 0.03$) for the HIWU condition compared to LIWU (Figure 6A and C). However, at post time trial, no significant differences were found between the conditions in RPE (Figure 6B) and ILS (Figure 6D).

Table 1. Participants characterization.

Participants	Age (years)	Body height (cm)	Body weight (kg)	Cooper test (m)	VO2max (ml/kg/min)	Practice time (years)	Warm-up running and sprint time (s)	
							250 m (70%)	250 m (100%)
A	27	173	60	3675	70.9	13	70	49
B	49	169	58	3360	63.8	15	77	54
C	40	168	62	3345	63.5	10	77	54
D	27	170	65	2948	54.6	8	87	61
E	32	165	52	3364	63.9	10	76	54
F	52	165	59	3175	59.7	23	81	57
G	36	167	67	3161	59.4	10	81	57
H	19	167	58	3638	70.0	1.5	72	49
I	23	170	63	3150	59.1	6	82	57
J	32	180	72	3147	59.1	5	82	57
K	35	173	67	3055	57.0	10	84	59
L	27	161	50	3741	72.3	5	69	48
M	39	170	67	3289	62.2	7	78	55
Mean	34	169	62	3311	62.7	9.5	78.2	54.7
SD	10	5	6	245	5.5	5.4	5.4	4.0

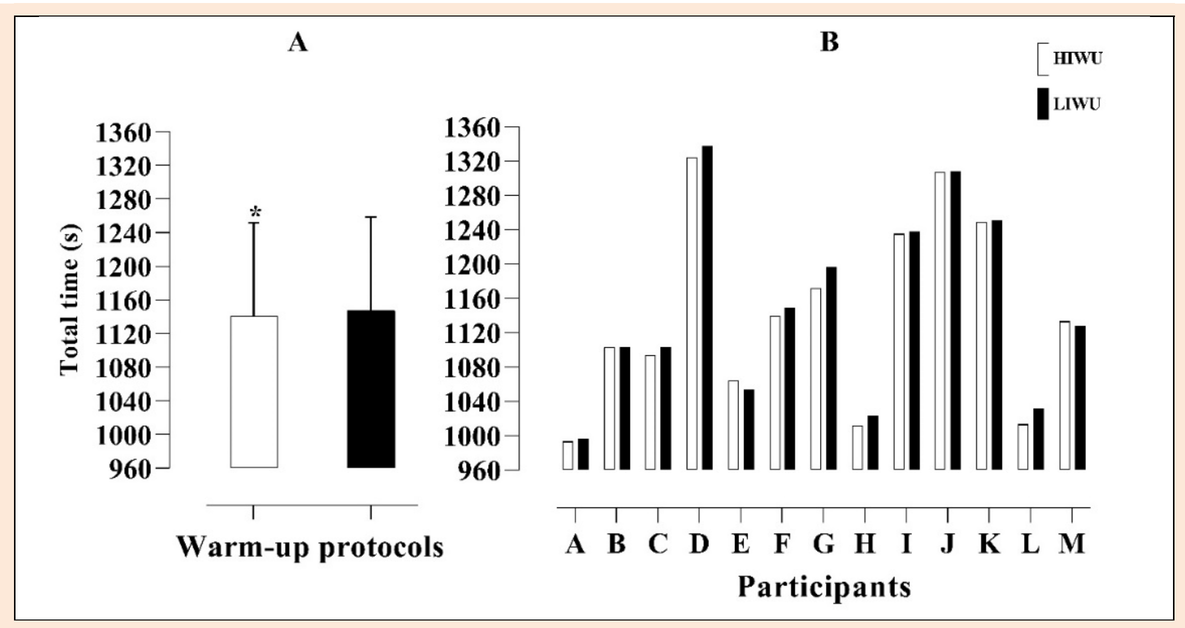

Figure 2. A) time trial (mean ± standard deviation) under HIWU and LIWU conditions. B) Average time per subject for completion of the time trial (seconds). A) time trial (mean ± standard deviation) in HIWU and LIWU conditions. *$p < 0.05$. B) Average time per subject for completion of the time trial (seconds).

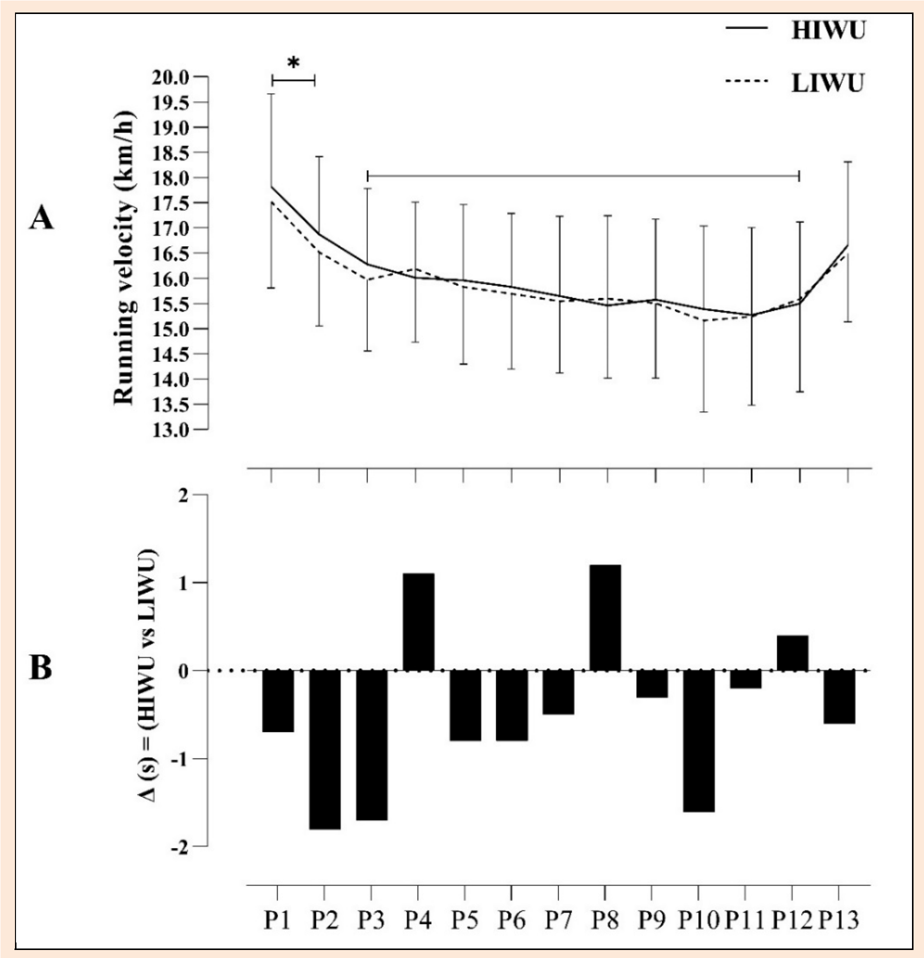

Figure 3. **A) Average running speed (km/h) in the 13 splits (mean ± standard deviation). B) Delta of the average times in seconds in the 13 split times (HIWU vs. LIWU). A) Average running speed (km/h) in the 13 splits (mean ± standard deviation): P1 = 200 m, P2 = 600 m, P3 = 1000 m, P4 = 1400 m, P5 = 1800 m, P6 = 2200 m, P7 = 2600 m, P8 = 3000 m, P9 = 3400 m, P10 = 3800 m, P11 = 4200 m, P12 = 4600 m and P13 = 5000 m.** *p < 0.05 vs. the interval P3-P12. B) Delta of the average times in seconds in the 13 split times (HIWU vs. LIWU).

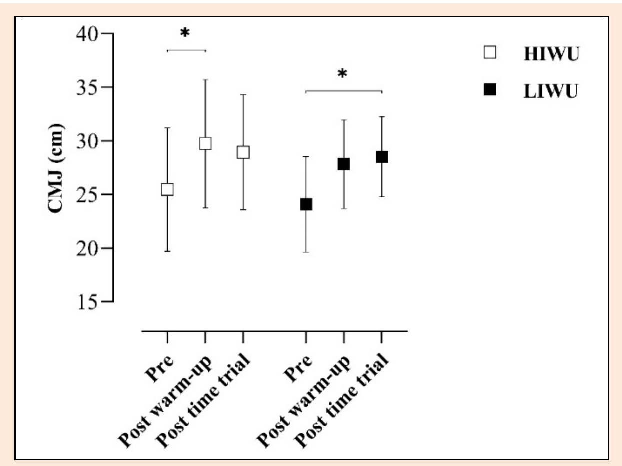

Figure 4. **Values in mean ± standard deviation of the performance in the CMJ, in the moments: pre, post warm-up and post time trial of 5000 m under the two conditions: HIWU and LIWU. Values in mean ± standard deviation of the performance in the CMJ, in the moments: pre, post warm-up and post time trial of 5000 m in the two conditions: HIWU and LIWU.** *p < 0.05.

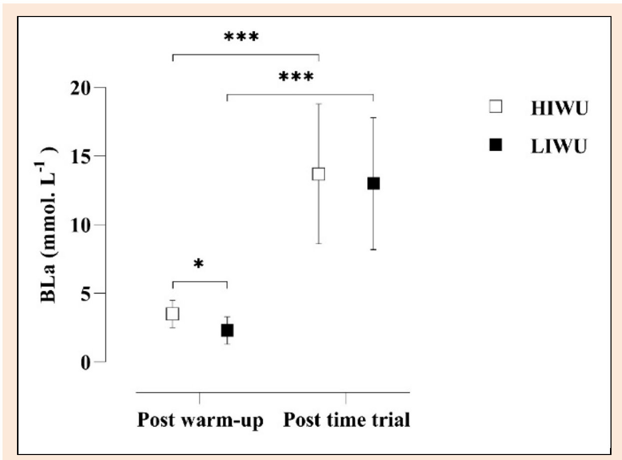

Figure 5. **Comparisons of changes in blood lactate accumulation between the two conditions (HIWU and LIWU), at the times: post warm-up and post time trial. Comparisons of changes in blood lactate accumulation between the two conditions (HIWU and LIWU), at the times: post warm-up and post time trial.** *p < 0.05 vs. LIWU. ***p < 0.001 vs. post warm-up.

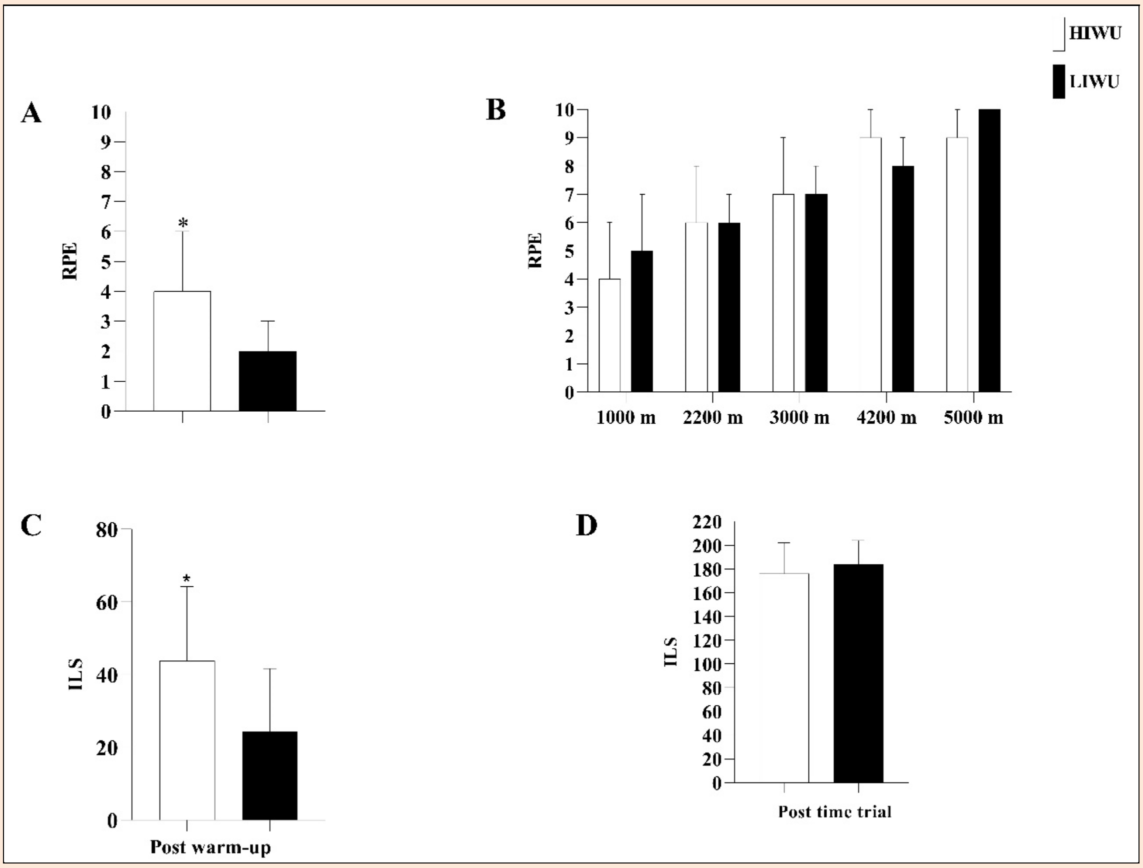

Figure 6. Values expressed as mean ± standard deviation: A) Rating of perceived exertion at post warm-up and B) Rating of perceived exertion at post 1000 m, 2200 m, 3000 m, 4200 m and 5000 m. C) Internal load of the session in the post warm-up moment. D) Internal load of the session at the moment post time trial. Values expressed as mean ± standard deviation: A) Rating of perceived exertion at post warm-up and B) Rating of perceived exertion at post 1000 m, 2200 m, 3000 m, 4200 m and 5000 m. C) Internal load of the session in the post warm-up moment. D) Internal load of the session at the moment post time trial. RPE = Rating of Perceived Exertion; ILS: Internal Load of the Session; *$p<0.05$ vs. LIWU.

Discussion

The present study aimed to verify the effect of high-intensity warm-up on the performance of trained endurance runners using the hypothesis that running performance would be improved by high-intensity warm-up compared to low-intensity warm-up. The main finding of this study was that the high-intensity warm-up improved the performance of the 5000 m runners by 6.4 s (0.5%) compared to the low-intensity warm-up. Therefore, our hypothesis was confirmed. Regarding individual responses, 10 out of 13 participants performed better under the HIWU condition. These results suggest possible changes in the warm-up structures of long-distance runners, who commonly perform warm-up at a low-intensity (García-Pinillos et al., 2019), diverging from the benefits obtained by our high-intensity protocol. Furthermore, our results corroborate to studies conducted on 800-1600 m runs and exhaustion tests (Ingham et al., 2013; Barnes et al., 2015; González-Mohíno et al., 2018; Paris et al., 2021). To our knowledge, this is the first study demonstrating improved performance in long-distance runners who had undergone a warm-up involving high-intensity running prior to a 5000 m time trial.

One of the factors associated with the performance of long-distance runners is the pacing strategy. Among the different possible strategies, the U pattern is more dominant in the 5000 m race, which is characterized by the greater speed at the beginning and end of the run (Tucker et al., 2006; Girard et al., 2013; Casado et al., 2021b). Corroborating this evidence, in our study, when analyzing pacing throughout the 13 splits only HIWU showed a significantly higher average running speed in the two first splits (600 m) compared with all of the following splits (1000-4600 m). This suggests that using HIWU before long-distance running may promote the renewal of adenosine triphosphate and the myosin cross-bridge cycling rate, enhancing muscle function (Bishop, 2003; McGowan et al., 2015), which may explain the improvements in performance in the initial phase of the run.

Additionally, there were no differences between the HIWU and LIWU, indicating a low influence of heat intensity on CMJ performance. There was, however, maintenance of muscular function in both groups in the intergroup analysis. In addition, the difference between the pre and post warm-up for CMJ was already expected. A further reason for improvement might be non-physiological, for example, that the runner chose the same speed in the warm-up as he would use in the competition.

Furthermore, is known that predominant factor in the 5000m run is aerobic (Tharp et al., 1997; Baumann et al., 2012; Blagrove et al., 2018). Aerobic performance is affected by VO_2 kinetics. HIWU may promote the increase in VO_2 kinetics, favoring gas exchange and metabolic reactions, such as the reduction of the slow component of VO_2max, therefore using O_2 more efficiently (Burnley et al., 2011; Ingham et al., 2013; Sousa et al., 2014; González-Mohíno et al., 2018).

To check the post warm-up metabolic condition, we measured blood lactate concentration (BLa), which showed values of 3.5 and 2.3 mmol·L^{-1} in HIWU and LIWU conditions, respectively. Our results corroborated the findings of Paris et al. (2021) . They identified levels of BLa, after different warm-up protocols: between 2.0-4.9 mmol·L^{-1} in the shortest times for completion of the 1600 m time trial, and when BLa ≥ 5.0 mmol·L^{-1}, when the time was longer. In this regard, the two warm-up protocols used in our study pointed out that, regardless of intensity applied, the protocols maintained controlled conditions for Onset of Blood Lactate Accumulation (OBLA).

Another important factor in the modulation of warm-up protocols for better performance is the transition period. Studies with protocols analogous to those used in our study have applied transitions between 18 and 20 min (Ingham et al., 2013; González-Mohíno et al., 2018; Paris et al., 2021). This structure was also adopted in the present study because it is similar to the competitive environment of runners who, after positioning themselves at the start, are unable to perform trots and short bursts. Thus, we adopted 18 min of recovery, consisting of a protocol of running drills performed three minutes before the trial to increase both body temperature and heart rate, components involved in the exercise readiness state (Andzel, 1982; Bishop, 2003; McGowan et al., 2015; Silva et al., 2018). When high-intensity warm-up protocols were not accompanied by a transition period of between 18-20 min, performance improvements were not observed (Zourdos et al., 2017; Takizawa et al., 2018).

Alterations caused by the warm-up protocols were observed in RPE and ILS. We identified a higher perceived exertion immediately after the HIWU (~17 km/h) compared to the LIWU (~12 km/h). Furthermore, the total distance of the protocol was 1250 m (25% of the volume performed in the time trial), suggesting an association between the volume and intensity of the warm-up with the increase in perceived exertion (Alsamir Tibana et al., 2019). However, even HIWU with higher RPE and ILS did not negatively influence performance during the time trial. We emphasize that the Borg Scale (Borg, 1998) and Foster (Foster, 1998) should be applied after the warm-up since they are efficient, low-cost methods for controlling the inherent components of running periodization: volume and intensity (Faelli et al., 2021). Controlling these variables may prevent overtraining and injuries (Boullosa et al., 2020).

The present findings and previous evidence (Ingham et al., 2013; Barnes et al., 2015; González-Mohíno et al., 2018; Paris et al., 2021) suggest that a high-intensity warm-up is associated with short-term performance improvements. Furthermore, future studies with long-distance runners and other warm-up intensities are needed to identify the possible maintenance of the benefits found in this study, expanding the levels of intensity that may be adopted during warm-up sessions. Studies should explore different populations, including women and elite runners, with methodologies directed towards biomechanical (stride frequency, amplitude, and cadence, among others) and physiological mechanisms, aiming to deepen the understanding of more components linked to the best performance associated with high-intensity warm-up protocols.

The study's main limitation was the estimation of warm-up intensity through the results obtained in the Cooper test (Cooper, 1968). Also, expired gas parameters were not available to the researchers. On the other hand, although this is an estimated measure of maximal oxygen consumption, it has been widely used as a practical method (Mayorga-Vega et al., 2016) and can be more easily replicated by teams and coaches. Furthermore, BLa levels and RPE after the warm-up protocols sustained the intensities according to what was prescribed and executed.

Conclusion

The study showed that a high-intensity warm-up protocol can improve the performance of trained endurance runners in a 5000 m run. Additionally, control of perceived exertion during warm-up is necessary. In light of these observations, we encourage coaches to develop warm-up protocols that promote performance improvements based on mechanistic and biological parameters.

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Key points

- Continuous running at high intensities (~17 km/h) during warm-up promotes improvement (6.4 s) in the 5000 m time trial performance of trained runners
- The high-intensity warm-up protocol improved pacing strategy during the 5000 m.

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