THE EFFECTS OF DIFFERENT WARM-UP VOLUMES ON THE 100-M SWIMMING PERFORMANCE: A RANDOMIZED CROSSOVER STUDY

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ABSTRACT

Neiva, HP, Marques, MC, Barbosa, TM, Izquierdo, M, Viana, JL, Teixeira, AM, and Marinho, DA. The effects of different warm-up volumes on the 100-m swimming performance: a randomized crossover study. *J Strength Cond Res* 29(11): 3026–3036, 2015—The aim of this study was to compare the effect of 3 different warm-up (WU) volumes on 100-m swimming performance. Eleven male swimmers at the national level completed 3 time trials of 100-m freestyle on separate days and after a standard WU, a short WU (SWU), or a long WU (LWU) in a randomized sequence. All of them replicated some usual sets and drills, and the WU totaled 1,200 m, the SWU totaled 600 m, and the LWU totaled 1,800 m. The swimmers were faster after the WU (59.29 seconds; confidence interval [CI] 95%, 57.98–60.61) and after the SWU (59.38 seconds; CI 95%, 57.92–60.84) compared with the LWU (60.18 seconds; CI 95%, 58.53–61.83). The second 50-m lap after the WU was performed with a higher stroke length (effect size [ES] = 0.77), stroke index (ES = 1.26), and propelling efficiency (ES = 0.78) than that after the SWU. Both WU and SWU resulted in higher pretrial values of blood lactate concentrations [La$^-$] compared with LWU (ES = 1.58 and 0.74, respectively), and the testosterone:cortisol levels were increased in WU compared with LWU (ES = 0.86). In addition, the trial after WU caused higher [La$^-$] (ES $\geq$ 0.68) and testosterone:cortisol values compared with the LWU (ES = 0.93). These results suggest that an LWU could impair 100-m freestyle performance. The swimmers showed higher efficiency during the race after a 1200-m WU, suggesting a favorable situation. It highlighted the importance of the [La$^-$] and hormonal responses to each particular WU, possibly influencing performance and biomechanical responses during a 100-m race.

KEY WORDS pre-exercise, time-trial, swimmers, Biomechanics, Physiology

INTRODUCTION

Warming-up before training or competition has become one of the most interesting topics for practitioners and recent research showed some positive effects on performance (13,26). It has been suggested that the rise in muscle temperature caused by priming exercises resulted in multiple physiological and metabolic changes that influences performance (3,4). Although it is a common practice among swimmers (23), little is known about the optimal procedures that would allow an increased preparedness for a given event. The different variables and the complexity of their relationship make it challenging to characterize the main features of the best warm-up (WU) technique. This fact may be the reason why literature found mixed results and remained a bit apart of this issue for some time (4,13,26).

Recently, Tomaras and MacIntosh (37) alerted to the adverse effects that an improperly designed WU protocol could cause in performance. These authors verified that a traditional WU in cycling induced higher fatigue and impaired peak power output, compared with a shorter WU protocol. Similar to cycling, in most sports, the WU is usually performed based on the athletes and coaches experiences, and perhaps it is not the best way to optimize performance. Specifically, in swimming, it is suggested that the swimmers should WU for a relatively moderate distance (i.e., 1,200 m) with the proper intensity (short race pace) and subsequent recovery time sufficient to avoid early fatigue during race (1,17,26). However, these recommendations were not scientifically clear and usually were followed by the suggestion for further investigation.

To the best of our knowledge, only Balilionis et al. (1) have studied the effect of different WU volumes on maximal

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29(11)/3026–3036

Journal of Strength and Conditioning Research

swimming performance. The authors compared the effects of a short WU (SWU; 91.44 m) and a longer WU (~1200 m) on 45.72-m freestyle performances and found that the longer one improved the swimmers' times by 1.22%. Nevertheless, no differences were found in the perceived effort and in the biomechanical analysis during the time trial. We could infer that a lower volume was not enough to cause sufficient physiological changes or that these results could be partially influenced by the familiarization with the longer WU. It is clear that this study intended mostly to analyze the swimmers performance and thus limited the physiological and biomechanical analysis. In addition, it was compared a usual WU procedure with a shorter WU that the swimmers were not accustomed. Thus, a possible understanding of the implementation of the different volumes of WU remains vague and unclear.

The WU could differently influence each particular race, and some literature point distinct effects on the 50- or the 100-m swimming events (1,27,28). Therefore, there is a need to investigate the impact of WU on longer swimming event times than literature presents. Also, few physiological and biomechanical variables were evaluated (1), and there is a need for understanding as much variables as we can get to better know this peculiar phenomenon. The WU is believed to influence biomechanical variables as stroke rate and length (17,27) and physiological variables as lactate, heart rate, or temperature (40,43). By analyzing multiple biomechanical and physiological effects of different WU practices, one can increase our knowledge to the swimmers responses and to provide better recommendations. For instance, the WU could influence some specific stress hormones as the cortisol and testosterone. On this, research has indicated these to be related to exercise intensity and duration (19,22), and their relationship with the body catabolic and anabolic processes could provide some important information about the WU effects in the swimmers. Besides this, both pre-exercise testosterone and cortisol concentrations might condition the anaerobic metabolism and perhaps influence the 100-m swimming race (11,35).

The present study was therefore conducted to compare the effects of 3 different WU volumes on the 100-m freestyle, in national-level swimmers. It was hypothesized that a reduced volume would not be enough to cause sufficient metabolic changes to optimize swimming performance. A secondary hypothesis was that a long WU (LWU) would increase muscular fatigue and affect performance.

METHODS

Experimental Approach to the Problem

The purpose of the present study was to evaluate the effects of an SWU, a standard WU, and an LWU volume on the 100-m freestyle, in high-level swimmers, in terms of performance, biomechanical, physiological, and psychophysiologic responses. The study followed a repeated measures design with each participant completing 3 time trials of 100-m freestyle in randomized order. Regarding the implemented WUs, it was verified that most studies of WUs protocols in competitive swimming selected volumes between 1,000 and 1,500 m (1,20,27). Based on those studies and in the knowledge of an experienced national swimming coach, it was structured a WU, comprising specific sets and drills. Using the total volume of the WU as a reference (1,200 m), the SWU was set at 50% of the WU (600 m) and the LWU, an increase of 50% over the standard volume (1,800 m). Moreover, the 100-m race was chosen because it is one of the most attractive swimming events, and scientific evidences showed that it is affected by the usual WU procedures, changing some physiological and biomechanical variables compared with no warming-up (27).

Subjects

Eligible participants were all national-level swimmers with >6 years of competitive experience. Eleven competitive male swimmers aged 15–25 years (mean ± *SD*: age 18.09 ± 3.30 years, 1.78 ± 0.07 m of height, 68.46 ± 7.98 kg of body mass, 9.55 ± 2.94 years of training background) participated in this study. All swimmers had previously competed at national swimming championships finals and had completed different WUs during the last years. A training volume of 35,500 ± 3,605 $m \cdot wk^{-1}$ (16.01 ± 1.21 hours) was performed during the current season. The personal best times in the 100-m freestyle event were 58.90 ± 2.37 seconds, which corresponds to 509.09 ± 63.74 FINA 2014 scoring points (long course). After local ethics board approval, ensuring compliance with the Declaration of Helsinki, the participants were informed about the study procedures, and a written informed consent was signed (or parent/guardian when subjects were younger than 18 years old). All swimmers were asked to maintain the same training, recovery, and diet routines during the days of assessment, avoiding strenuous exercise and abstaining from smoking and consuming caffeine 48 hours before testing.

Procedures

All the procedures took place at the same time of day (morning) in a 50-m indoor swimming pool with a water temperature of 27.53 ± 0.06° C, air temperature of 27.86 ± 0.14° C, and 61.33 ± 0.58% of humidity (measured before each test). Each swimmer was randomly assigned to one WU procedure (factor), and the use of competition swimsuits was allowed. The trials were performed individually to prevent pacing or tactics effects, with 48 hours between the conditions tested. After arriving at the pool, the swimmers remained seated for 5 minutes, with the legs uncrossed, to assess baseline measurements of heart rate, cortisol, testosterone, tympanic temperature, and blood lactate concentrations. Day-to-day intraclass correlation coefficients as a test of the reliability of the baseline measurements of heart rate, $[La^-]$, cortisol, testosterone, testosterone:cortisol ratio, and tympanic temperature were ICC > 0.90. Then, 3 different types of WU protocols were used (Table 1) with different

Table 1. Standard warm-up (WU), short warm-up (SWU), and long warm-up (LWU) protocols.

WU	SWU	LWU	Task description
300 m	150 m	500 m	Normal–breathing in the 5th stroke–Normal
4 × 100 m at 1:50	2 × 100 at 1:50	6 × 100 at 1:50	25 m kick–25 m increased stroke length
8 × 50 m at 1:00	4 × 50 at 1:00	12 × 50 at 1:00	50 m drill–50 building up velocity–25 race pace/25 easy–25 race pace/25 easy
100 m	50 m	100 m	Easy swim

total swimming volumes and identical intensities. Heart rate and ratings of perceived exertion (RPE) were monitored during the WUs to ensure the same intensity between the 3 conditions. After 10 minutes of passive rest, seated, and legs uncrossed, the swimmers performed the 100-m freestyle time trial.

Final Performance and Race Splits. In each trial, the swimmer was requested to set on the starting block and take off after official verbal commands and the starting signal. A timing system (Omega SA, Corgémont, Switzerland) was used to time the 100-m trials. As a backup, time trials were also clocked with a stopwatch used by an experienced swimming coach and a video camera (Casio Exilim Ex-F1, $f = 30$ Hz). The camera was placed at 15 m, perpendicular to lane 7, and it was used to assess the 15-m time over this distance.

Kinematics. Another camera (Casio Exilim Ex-F1, $f = 30$ Hz) was placed poolside at the 25-m mark of the swimming pool to record the time to swim 10 m in each 50-m lap (between the 15th and 25th m) and afterward to determine the swimming velocity. Two different and experienced researchers assessed the stroke frequency (SF) with a stroke counter (MC 815; Golfinho Sports, Aveiro, Portugal) from 3 consecutive stroke cycles within this 10 m. SF was converted to International System Units (Hz) for further analysis. The stroke length (SL) was calculated by dividing the velocity and the SF assessed during the 10 m (10).

Efficiency. The stroke index (SI), considered one of the swimming stroke efficiency indexes, was computed as the product of the velocity of the swimmer and the corresponding SL (9). The propelling efficiency (η_p) was also estimated by (41):

$$\eta_p = ([0.9 \times v]/[2\pi \times SF \times l]) \times 2/\pi,$$

where v is the swimming velocity ($m \cdot s^{-1}$), SF is the stroke frequency (Hz), and l is the arm length (m). The l is computed trigonometrically by measuring the arm length and considering the average elbow angles during the insweep of the arm pull as reported by Zamparo et al. (42).

Metabolic, Cardiovascular and Psychophysiologic Variables. Capillary blood samples for (La-) assessment (Accutrend Lactate; Roche, Mannheim, Germany) were collected from the fingertip after the WU protocol (first minute), immediately before the trial (ninth minute) and 3, 10, 20, and 30 minutes after the trial. The heart rate was assessed before, during, and after each WU (first minute), before the trial (ninth minute), and during the 30 minutes of recovery (every minutes) after the swimming test (Vantage NV; Polar, Kempele, Finland). During that time, the swimmers remained seated and were not allowed to move or take off the swimsuit. In addition, the RPE was recorded during the WU exercises (after each set), after the WU, and after each test using Borg 6- to 20-point scale (6).

Temperature. Tympanic temperature measurements were taken before the WU; after the WU (1 minute); immediately before the trial; and 1, 10, 20, and 30 minutes after the trial. This is a good indicator of brain temperature, which controls body temperature (29); each swimmer's tympanic temperature was taken 3 times, and the maximal value was recorded (ThermoScan IRT 4520; Braun, Kronberg, Germany). The thermometers had a measuring accuracy of 0.2° C for temperatures between 32.0° C and 42.0° C.

Hormonal Variables. Saliva samples were collected during the baseline evaluation, between the WU and trial, immediately after the 100 m and at the 30th minute of recovery. The participants were seated and leaning forward, providing saliva samples using the passive drool method. Samples were collected directly through a 5-m plastic drinking straw into 10-mL plastic screw top tubes, and all samples were kept cold immediately after collection (2° C) and then frozen (−20° C) until they were assayed. Every collection tube was identified with numbers and letters that corresponded to each participant, WU procedure, and collection point. The minimum collection time was 3 minutes for each subject to allow for the collection of a sufficient sample volume. No drinking was allowed, and procedures were conducted at the same time of day to avoid circadian influences on performance. The salivary cortisol and salivary testosterone

Table 2. Mean ± *SD* values (95% confidence limits) of the blood lactate concentrations [La$^-$], heart rate, ratings of perceived exertion (RPE), tympanic temperature, cortisol, testosterone, and testosterone:cortisol ratio (T:C ratio) after warm-up (after WUP) and before trial (except RPE, cortisol, testosterone, and T:C ratio).*

	Standard warm-up (WU)	Short warm-up (SWU)	Long warm-up (LWU)	WU vs. SWU	WU vs. LWU	SWU vs. LWU
[La$^-$] (mmol·L^{-1})						
After WUP	5.52 ± 1.29 (4.65, 6.38)	5.01 ± 0.95 (4.37, 5.65)	4.01 ± 0.74 (3.56, 4.55)	ES = 0.43, $p = 0.19$	ES = 1.13, $p = 0.01$	ES = 1.23, $p < 0.01$
Pretrial	4.23 ± 0.71 (3.75, 4.70)	3.71 ± 0.86 (3.13, 4.28)	3.19 ± 0.61 (2.78, 3.60)	ES = 0.47, $p = 0.15$	ES = 1.58, $p < 0.01$	ES = 0.74, $p = 0.04$
Heart rate (b·min^{-1})						
After WUP	128 ± 13 (118, 137)	118 ± 21 (103, 133)	122 ± 11 (114, 130)	ES = 0.63, $p = 0.08$	ES = 0.53, $p = 0.13$	ES = 0.23, $p = 0.48$
Pretrial	115 ± 19 (98, 133)	109 ± 17 (94, 124)	112 ± 10 (103, 121)	ES = 0.32, $p = 0.17$	ES = 0.18, $p = 0.31$	ES = 0.17, $p = 0.40$
Tympanic Temperature (° C)						
After WUP	34.73 ± 0.65 (34.27, 35.19)	34.25 ± 0.29 (34.04, 34.46)	34.23 ± 0.21 (34.08, 34.38)	ES = 0.65, $p = 0.03$	ES = 0.78, $p = 0.04$	ES = 0.11, $p = 0.83$
Pretrial	36.44 ± 0.49 (36.11, 36.76)	36.26 ± 0.33 (36.04, 36.48)	36.36 ± 0.47 (36.05, 36.68)	ES = 0.41, $p = 0.21$	ES = 0.16, $p = 0.64$	ES = 0.39, $p = 0.23$
RPE						
After WUP	7.91 ± 1.51 (6.89, 8.93)	6.73 ± 1.01 (6.05, 7.41)	7.36 ± 1.69 (6.23, 8.50)	ES = 0.82, $p = 0.02$	ES = 0.27, $p = 0.51$	ES = 0.43, $p = 0.17$
Cortisol (nmol·L^{-1})						
After WUP	5.18 ± 2.18 (3.62, 6.74)	6.08 ± 2.54 (4.27, 7.89)	6.40 ± 3.21 (4.10, 8.70)	ES = 0.36, $p = 0.28$	ES = 0.54, $p = 0.12$	ES = 0.10, $p = 0.76$
Testosterone (pmol·L^{-1})						
After WUP	330.65 ± 128.20 (238.94, 422.36)	309.40 ± 121.85 (222.24, 396.57)	278.80 ± 93.01 (212.27, 345.34)	ES = 0.33, $p = 0.35$	ES = 0.70, $p = 0.06$	ES = 0.39, $p = 0.24$
T:C Ratio						
After WUP	68.70 ± 30.49 (46.88, 90.51)	58.68 ± 32.25 (35.61, 81.75)	49.02 ± 16.94 (36.90, 61.15)	ES = 0.25, $p = 0.50$	ES = 0.76, $p = 0.02$	ES = 0.29, $p = 0.37$

*p values and effect size (ES) are presented ($n = 11$).

TABLE 3. Mean ± *SD* values (95% confidence limits) of the 100- and 50-m lap times, starting time (15 m), stroke frequency, stroke length, stroke index, and propelling efficiency (η_p) in the 100-m trial after the 3 different warm-up protocols.*

	Standard warm-up (WU)	Short warm-up (SWU)	Long warm-up (LWU)	WU vs. SWU	WU vs. LWU	SWU vs. LWU
100 m (s)	59.29 ± 1.95 (57.98, 60.61)	59.38 ± 2.18 (57.91, 60.84)	60.18 ± 2.46 (58.53, 61.83)	ES = 0.09, $p = 0.78$	ES = 0.95, $p = 0.01$	ES = 1.12, $p < 0.01$
1st 50 m (s)	28.04 ± 1.38 (27.12, 28.97)	28.01 ± 1.16 (27.23, 28.79)	28.64 ± 1.42 (27.69, 29.60)	ES = 0.03, $p = 0.91$	ES = 0.59, $p = 0.08$	ES = 1.31, $p < 0.01$
2nd 50 m (s)	31.25 ± 1.75 (30.08, 32.43)	31.37 ± 1.47 (30.38, 32.36)	31.54 ± 1.69 (30.41, 32.67)	ES = 0.10, $p = 0.76$	ES = 0.24, $p = 0.41$	ES = 0.18, $p = 0.49$
15 m (s)	7.11 ± 0.37 (6.86, 7.36)	7.25 ± 0.34 (7.02, 7.48)	7.19 ± 0.36 (6.95, 7.44)	ES = 1.09, $p < 0.01$	ES = 0.68, $p = 0.04$	ES = 0.67, $p = 0.08$
Stroke frequency (Hz)						
1st 50 m	0.96 ± 0.08 (0.91, 1.01)	0.94 ± 0.08 (0.88, 0.99)	0.93 ± 0.09 (0.87, 0.99)	ES = 0.64, $p = 0.02$	ES = 0.73, $p = 0.02$	ES = 0.25, $p = 0.59$
2nd 50 m	0.76 ± 0.06 (0.72, 0.71)	0.78 ± 0.05 (0.74, 0.81)	0.76 ± 0.05 (0.72, 0.80)	ES = 0.41, $p = 0.40$	ES = 0.23, $p = 0.46$	ES = 0.52, $p = 0.18$
Stroke length (m)						
1st 50 m	2.21 ± 0.19 (2.08, 2.34)	2.22 ± 0.21 (2.07, 2.36)	2.27 ± 0.24 (2.10, 2.43)	ES = 0.04, $p = 0.89$	ES = 0.58, $p = 0.11$	ES = 0.63, $p = 0.07$
2nd 50 m	1.99 ± 0.17 (1.87, 2.10)	1.91 ± 0.17 (1.80, 2.02)	1.98 ± 0.15 (1.88, 2.08)	ES = 0.77, $p = 0.03$	ES = 0.16, $p = 0.69$	ES = 0.58, $p = 0.08$
Stroke index ($m^2 \cdot c^{-1} \cdot s^{-1}$)						
1st 50 m	4.68 ± 0.56 (4.31, 5.06)	4.58 ± 0.61 (4.17, 4.99)	4.76 ± 0.70 (4.29, 5.23)	ES = 0.34, $p = 0.28$	ES = 0.31, $p = 0.37$	ES = 0.80, $p = 0.03$
2nd 50 m	3.02 ± 0.38 (2.76, 3.27)	2.83 ± 0.37 (2.58, 3.08)	2.97 ± 0.31 (2.76, 3.17)	ES = 1.26, $p < 0.01$	ES = 0.29, $p = 0.35$	ES = 0.62, $p = 0.08$
η_p (%)						
1st 50 m	35.05 ± 3.16 (32.92, 37.17)	35.11 ± 3.64 (32.67, 37.55)	35.94 ± 4.16 (33.14, 38.74)	ES = 0.04, $p = 0.90$	ES = 0.54, $p = 0.10$	ES = 0.64, $p = 0.06$
2nd 50 m	31.85 ± 2.53 (30.15, 33.54)	30.62 ± 2.87 (28.69, 32.55)	31.72 ± 2.41 (30.10, 33.34)	ES = 0.78, $p = 0.03$	ES = 0.12, $p = 0.70$	ES = 0.59, $p = 0.08$

*p values and effect size (ES) are presented ($n = 11$).

concentrations were determined by enzyme-linked immunosorbent assay using commercially available kits (Salimetrics, State College, PA, USA). The sensitivity of the kits was 0.08 nmol·L^{-1} and 3.46 pmol·L^{-1} for cortisol and testosterone, respectively. The mean intra-assay coefficients of variation were 2.43 and 3.19% for cortisol and testosterone, respectively. The mean interassay coefficients of variation were 1.39 and 4.73% for cortisol and testosterone, respectively.

Statistical Analyses

Standard statistical methods were used for the calculation of mean ± *SD*, and 95% confidence intervals for all variables. The normality of all distributions was verified using Shapiro-Wilk tests. The effect of the 3 WU procedures was analyzed by an ANOVA for repeated measures, with sphericity checked using Mauchly's test. When the assumption of sphericity was not met, the significance of *F* ratios was adjusted according to the Greenhouse-Geisser procedure. Post hoc paired *t*-tests were run to further investigate the effect of each condition. A nonparametric Friedman test with post hoc Wilcoxon signed-rank test was applied whenever a normality of distributions was not found. Analysis of the Cohen d effect size (ES) for repeated measures was accomplished using the G-Power 3.1.3 for Windows (University of Kiel, Germany) for each pair of conditions tested. An effect size 0.2 was deemed small, 0.5 medium, and 0.8 large (8). The limits of agreement between the 100-m time in the 3 conditions were derived according to the literature (5). The level of statistical significance was set at $p \leq 0.05$.

RESULTS

Acute Effects of Different Types of Warm-up Stimuli

After the main task, there were no differences in the heart rate ($F_{2,20} = 3.08, p = 0.07$) between the WU (152 ± 11 b·min^{-1}), SWU (144 ± 17 b·min^{-1}), and LWU (146 ± 18 b·min^{-1}) and in the RPE values ($F_{2,20} = 3.08$, $p = 0.15$; 13.82 ± 1.72, 13.45 ± 2.02 and 13.36 ± 1.91, respectively), reflecting the similar intensity between WUs. Table 2 presents a comparison between the [La$^-$], the heart rate, the tympanic temperature, the salivary cortisol and testosterone concentrations, and their ratio after the 3 WU procedures and immediately before the trial. The conditions tested resulted in higher values of [La$^-$] after the WU and SWU compared with the LWU ($F_{2,20} = 9.41$, $p < 0.01$), and these differences remained until the trial started ($F_{1.35,13.46} = 8.34$, $p < 0.01$). In addition, the perceived effort was higher for the WU than the SWU although it remained very low for all the conditions tested, and the higher tympanic temperatures were reached with the WU condition ($\chi^2_2 = 9.80$, $p < 0.01$). These differences caused by the different WU stimuli lapsed during the recovery time between the WU and the time trial.

Final Performance and Race Splits

Table 3 presents the results recorded during the trial. It was shown that the 100-m time trial was different between conditions ($F_{2,20} = 6.57$, $p < 0.01$). The swimmers were 1.46 ± 1.54% and 1.34 ± 1.24% faster after the WU and SWU, respectively, compared with the LWU. In addition, the first 50-m lap time was different between conditions ($F_{2,20} = 4.00$, $p = 0.04$) in opposition to the second lap that showed no differences ($F_{2,20} = 0.41$, $p = 0.67$). However, this second lap showed differences in variables that are usually associated with swimming efficiency, as SL ($F_{2,20} = 4.15$, $p = 0.03$), SI ($F_{2,20} = 5.80$, $p = 0.01$), and η_p ($F_{2,20} = 4.24$, $p = 0.03$), with higher values after the WU compared with the SWU.

The individual differences between the WU, SWU, and LWU for the 100-m performances are presented in Figure 1. Six swimmers were faster after the WU compared with the SWU, 9 swimmers were faster after the WU compared with the LWU, and all the swimmers were faster after the SWU compared with the LWU.

Recovery After the Trial

The 3 conditions tested caused different responses after the trial in the [La$^-$] values ($F_{2,20} = 4.41$, $p = 0.03$), in the heart

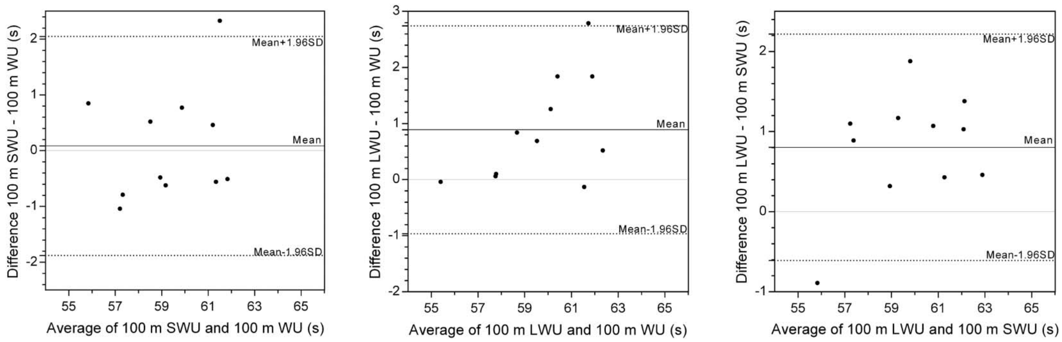

Figure 1. Bland-Altman plots representing the 100-m time in the 3 trial conditions: with standard warm-up (WU), with short warm-up (SWU), and with long warm-up. Average difference line (solid line) and 95% confidence interval (dashed lines) are indicated ($n = 11$).

TABLE 4. Mean ± *SD* values (95% confidence limits) of the blood lactate concentrations [La⁻], heart rate, ratings of perceived exertion (RPE), tympanic temperature, cortisol, testosterone, and testosterone:cortisol ratio (T:C) immediately after the trial.*

	Standard warm-up (WU)	Short warm-up (SWU)	Long warm-up (LWU)	WU vs. SWU	WU vs. LWU	SWU vs. LWU
[La⁻] (mmol·L^{-1})	12.25 ± 2.28 (10.72, 13.78)	10.77 ± 2.44 (9.13, 12.41)	10.36 ± 2.32 (8.80, 11.92)	ES = 0.68, $p = 0.05$	ES = 0.69, $p = 0.04$	ES = 0.25, $p = 0.42$
Heart rate (b·min^{-1})	169 ± 9 (164, 175)	165 ± 12 (157, 173)	172 ± 10 (165, 179)	ES = 0.53, $p = 0.08$	ES = 0.24, $p = 0.21$	ES = 0.80, $p = 0.05$
RPE	18.36 ± 1.21 (17.55, 19.17)	18.45 ± 0.93 (17.83, 19.08)	18.63 ± 0.81 (18.09, 19.18)	ES = 0.09, $p = 0.74$	ES = 0.24, $p = 0.37$	ES = 0.17, $p = 0.53$
Tympanic temperature (° C)	34.96 ± 0.73 (34.48, 35.45)	34.58 ± 0.45 (34.28, 34.88)	34.58 ± 0.52 (34.23, 34.93)	ES = 0.48, $p = 0.08$	ES = 0.58, $p = 0.06$	ES = 0.00, $p = 0.80$
Cortisol (nmol·L^{-1})	5.01 ± 1.85 (3.69, 6.34)	5.68 ± 2.17 (4.12, 7.23)	6.37 ± 2.99 (4.23, 8.51)	ES = 0.28, $p = 0.40$	ES = 0.38, $p = 0.26$	ES = 0.32, $p = 0.33$
Testosterone (pmol·L^{-1})	371.49 ± 143.35 (275.18, 467.80)	324.95 ± 101.87 (256.51, 393.39)	329.01 ± 112.14 (253.67, 404.35)	ES = 0.33, $p = 0.29$	ES = 0.36, $p = 0.26$	ES = 0.04, $p = 0.89$
T:C Ratio	74.55 ± 32.08 (51.60, 97.51)	61.69 ± 26.14 (43.00, 80.39)	53.66 ± 16.41 (41.91, 65.40)	ES = 0.72, $p = 0.09$	ES = 0.72, $p = 0.01$	ES = 0.33, $p = 0.45$

*p values and effect size (ES) are presented ($n = 11$).

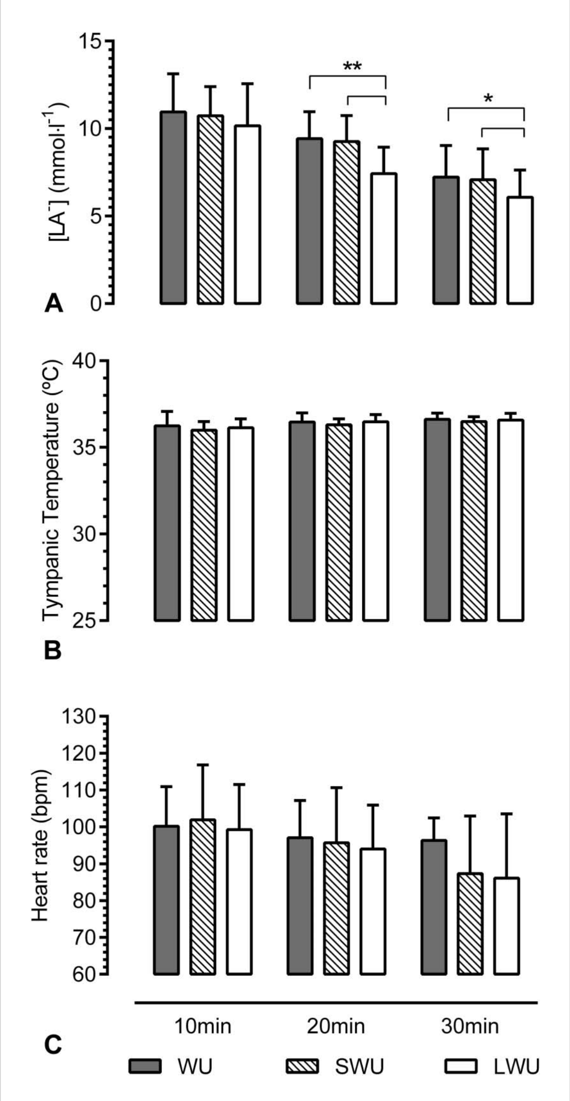

Figure 2. Comparison between the blood lactate concentrations [La⁻] (A), tympanic temperature (B), and heart rate (C) values, assessed during the 30 minutes of recovery after the 100 m, with standard warm-up (WU), short warm-up (SWU), and long warm-up (LWU). $*p \le 0.05$, $**p \le 0.01$, $n = 11$.

rate ($\chi_2^2 = 6.55$, $p = 0.04$), and in the testosterone:cortisol ratio ($\chi_2^2 = 7.40$, $p = 0.03$), as presented in Table 4. In the WU condition, [La⁻] values were 1.48 ± 0.66 mmol·L^{-1} higher than those with the SWU and 1.89 ± 0.82 mmol·L^{-1} higher than those with the LWU. Although the salivary hormones were not different between trials, their ratio values were higher after the WU compared with the LWU.

No differences were found in tympanic temperature after 10 minutes ($F_{2,20} = 0.88$, $p = 0.43$), 20 minutes ($F_{2,20} = 1.96$, $p = 0.17$), and 30 minutes ($F_{2,20} = 1.02$, $p = 0.38$) of recovery. The same effect happened with heart rate values 10 minutes ($F_{2,16} = 0.10$, $p = 0.91$), 20 minutes ($F_{2,18} = 0.14$, $p = 0.88$), and 30 minutes ($F_{2,10} = 1.17$, $p = 0.35$) after finishing the time trial in the 3 conditions tested. However, as presented in Figure 2, [La⁻] was lower after the LWU at the 20th and 30th minute of recovery (7.43 ± 1.51 and 6.07 ± 1.56 mmol·L^{-1}, respectively) compared with the SWU (9.25 ± 1.49 and 7.07 ± 1.77 mmol·L^{-1}, respectively) and the WU (9.43 ± 1.54 and 7.23 ± 1.80 mmol·L^{-1}, respectively).

After the recovery, there were no differences in cortisol ($F_{2,20} = 1.10$, $p = 0.35$), testosterone ($F_{2,20} = 2.05$, $p = 0.15$), or testosterone:cortisol ratio ($F_{2,12} = 2.12$, $p = 0.17$) between the WU (7.67 ± 5.20 nmol·L^{-1}, 390.32 ± 86.01 pmol·L^{-1}, and 72.51 ± 46.29, respectively), SWU (6.30 ± 2.99 nmol·L^{-1}, 352.27 ± 81.47 pmol·L^{-1}, and 63.52 ± 27.05, respectively), and LWU (8.19 ± 4.90 nmol·L^{-1}, 355.77 ± 105.69 pmol·L^{-1}, and 55.14 ± 28.63, respectively).

DISCUSSION

The purpose of the present study was to compare the effects of different WU volumes on maximal 100-m freestyle swimming performance that represents performance at the extreme-intensity domain. Our main findings could be summarized as follows: (a) the 3 WUs caused different physiological adaptations, with higher [La⁻] values in WU and SWU and higher testosterone:cortisol levels in WU in the pretrial momentum; (2) the LWU resulted in impaired maximal performances, even when compared with the SWU, and this did not result in different performances compared with the WU; (c) within the conditions with better performances, different biomechanical patterns were found, and the swimmers' efficiency was improved in WU during the second lap; and (d) a higher testosterone:cortisol ratio levels during recovery after trial could indicate an increased anabolic state, contributing to a faster initial recovery in WU condition.

Regarding the main aim of the present study, swimmers performed faster in the 100-m freestyle after the WU and SWU, and these differences were mainly achieved in the first 50-m lap. Furthermore, we show in Figure 1 that none of the participants achieved a better time after the LWU compared with the SWU, with only 2 swimmers faster after the LWU than the WU. This individual comparison between the WU and SWU denotes the aforementioned similarity between performances (45 and 55% faster for the SWU and WU, respectively). These findings are in line with the recent approaches to WU that revealed a diminished power production and impaired performances after an LWU maybe because of increased muscle fatigue (37). On the other hand, Balilionis et al. (1) found better swimming times on short races (45.72 m) after a regular WU compared with a shorter one. However, those best results were achieved after a WU that was usually performed by the swimmers and comparing it to another of extremely low volume (91.44 m of total volume), perhaps insufficient to cause the necessary metabolic changes.

An interesting fact was that after the SWU, the performance of the first 15 m was impaired. It can be hypothesized that the lower volume was not sufficient to cause significant metabolic changes or that the velocity stimulus was not enough to effectively potentiate the initial power performance (33). However, these differences in the first 15 m disappeared, and at the half-way point of the time trial, both the WU and SWU were responsible for moderated better lap times compared with the LWU ($ES \geq 0.59$). Thus, this finding should be taken into consideration based on the race strategy (e.g., if one is a quick or slow starter).

The WU duration also influenced the stroke mechanics of the swimmers. Too short or too LWUs seemed to impair the SF at the beginning of the time trial. An optimal WU may induce motor neuron excitability that improves the rate of force development, and this helped the swimmers to attain higher SF in the first 50-m lap after the WU. Probably to compensate for the inability to increase the SF, a higher SL was used in the LWU and caused higher SI values in that lap. Moreover, our results showed that the WU resulted in increased SL, SI, and η_p during the second 50-m lap, variables commonly associated with a low total energy expenditure required to displace the body over a given distance (2). Those higher values revealed an ability of the swimmers to maintain a high swimming efficiency in the second lap after the WU compared with the SWU. The swimmers are able to readily adjust their technique and patterns of propulsive forces produced according to their constraints and contexts (2), and perhaps an improved energy management enables the swimmers to maintain their technical ability over the time trial and optimize their biomechanical pattern (17).

The observed performances could somehow be caused by the different physiological responses to the 3 WUs tested. The swimmers reached the lower $[La^-]$ values after the LWU. The longer time elapsed during the LWU could allow a greater recovery, and swimming at low intensities increased the stimulation of aerobic instead of anaerobic metabolism and the rate of lactate clearance (15,38). In addition, this longer time keeping the swimmers' bodies inside water at 27° C led to lower tympanic temperatures than WU. In the case of SWU, also with lower values of tympanic temperature compared with WU, one can speculate that it was not long enough to trigger a temperature response. Considering the importance of the body temperature effect as a resultant of WU (3), it seemed that the relationship between the WU characteristics (i.e., duration, intensity, rest) and the time spent in the water could be more appropriate in the case of the WU. In addition, it should be noted that the intensity of WU was not different between conditions as demonstrated by the similar values of heart rate and RPE after the main task. Nevertheless, after the WU they performed differently, with lower RPE values after SWU compared with WU. The shorter volume and time of SWU could have influenced the swimmers to perceive lower RPE values after warming-up.

The most relevant results were those verified pretrial, influencing the homeostasis of the swimmers immediately before the race and thus the performance. It was interesting to notice that $[La^-]$ values were higher in WU and SWU compared with LWU. Traditionally, the accumulation of $[La^-]$ and most precisely of the hydrogen ions is pointed as a major cause of muscle fatigue and impaired performance (7). On both cases, our values were under the 4.70 $mmol \cdot L^{-1}$, and it seemed not enough to cause the different acidosis needed to influence performance, which should drop >0.4 pH units (7). On the opposite way, one could speculate that an increase in $[La^-]$ could benefit the performance. Research documented that $[La^-]$ caused a greater release of oxygen from hemoglobin for working muscles, an enhancement of blood flow, and alter the neurologic feedback for energy production (12,34). These effects could emerge in an optimized aerobic stimulation during a race where this energy metabolism could contribute with 43% of the energy expenditure (32). Furthermore, the lactate shuttle inside muscle fibers could facilitate the use of lactate as fuel by the other muscle fibers (14) and/or the acidosis resultant of glycolysis could function as a protective mechanism on potassium-depressed muscle contractions (31). The muscle force decrease known with increased potassium levels in extracellular milieu seems to be completely reestablished when lactic acid and salbutamol are added, thus suggesting a positive action of this acid on protection of muscles against fatigue (31). These effects are still controversial; however, our higher pretrial values in WU and SWU could benefit from some of these effects and help to improve the swimmers performance.

The other physiological variable altered in pretrial momentum was related with the hormonal response. First, one should report that cortisol and testosterone levels corresponded to the normal range of values for men presented in the literature (16,18). The swimmers attained higher values of testosterone:cortisol ratio in WU compared with LWU condition mostly because of the large magnitude of the differences found in testosterone values ($ES = 0.70$). The differences found before trial between conditions tested could contribute for the improved performances on the 100-m trial in the WU condition. For instance, the higher level of testosterone responsible for the increased testosterone:cortisol ratio in WU could directly influence force production by facilitating neurotransmitter release (25) and perhaps contributing for the higher SF in the beginning of the race. In addition, the abovementioned higher efficiency found in the second 50-m lap could occur because of the delay in fatigue that research associated with an elevated acute testosterone response pre-exercise (30). These suggestions could also be supported by the findings of Mujika et al. (24) in a longitudinal swimming in swimming. These authors found correlations between increases in testosterone:cortisol ratio and improvements in swimming performance during a competitive season.

The faster performances in the WU trial resulted in higher $[La^-]$ values. It is known that an increase in $[La^-]$ during exercise could represent an increased production and release from muscles, a decreased uptake and removal, or a greater increase in production and release in comparison to uptake and removal (15). Therefore, this increased [La$^-$] could be caused by the augmented contribution of anaerobic metabolism during 100 m after the WU. For instance, the higher initial SF in the WU led the swimmers to spend more energy anaerobically. This is commonly associated with a higher energy cost (2), and the use of high SF at high swimming velocities stimulates the anaerobic lactic and alactic metabolism (36).

The differences in [La$^-$] after the 100-m trial disappeared during the first 10 minutes of recovery, suggesting an augmented capacity of recovering in the first instants after trial in WU condition. The hormonal responses are in accordance with this hypothesis with higher testosterone:cortisol ratio levels after WU (ES = 0.72). According to the literature, an increase in this variable may be related to elevated anabolic activity, and a decrease may indicate a more catabolic state (39). For instance, an augmented testosterone increases protein synthesis, whereas higher cortisol promotes the breakdown of muscle protein (21). Thus, one could say that a faster rate of recovery from exercise exists in the first minutes, in the WU condition. In addition, this recovery could be assisted by the higher heart rate observed immediately after the trial. There are reports in the literature that the increased heart rate leads to an increased blood flow to the working muscle (38). This is believed to enhance lactate removal by allowing a faster distribution to the sites of removal mentioned previously. Moreover, the heart rate could have been important to the increased [La$^-$] removal in the following period. In the LWU condition, [La$^-$] values were lower in the 20th and 30th minute of recovery, maybe because of the similar values to WU verified after the trial. Considering that there was no effects caused by testosterone ratio levels in LWU, heart rate alone could led to a later recovery response.

In conclusion, the swimmers were faster after the WU and SWU, suggesting that a LWU can impair the sprinting performance in the 100 m freestyle event. Regarding the 2 conditions showing better time trials, the WU showed a higher swimming efficiency and an optimized recovery in the first minutes after the trial. Immediately before the trial, [La$^-$] and testosterone:cortisol ratio were increased in WU condition and this could influenced performance and perhaps the biomechanical stroke pattern of the swimmers during the race. Also, the increased heart rate and testosterone:cortisol ratio seemed to be the main influencing factors of recovery, allowing a faster initial recovery after trial in the WU condition. These were the novel findings of this study but we also should be aware that there was a considerable inter-individual variability in the response to different WU designs. The counterbalanced distribution of the swimmers by the testing conditions diminished some possible day-to-day performance effects and faded some possible other effects, increasing the reliable of this study. Further investigation should be developed to understand the best condition for each swimmer and try to design a WU set accordingly.

PRACTICAL APPLICATIONS

The results seem to suggest that high-level male swimmers should benefit from a WU of up to 1200 m, with an increased efficiency during the trial and faster recovery immediately after race. Furthermore, our data highlight the need for tailored and customized WU designs because swimmers had different individual responses. Alternatively, if individual WUs are not feasible for some reason, practitioners should consider shorter distances. Coaches usually have several swimmers warming-up at the same time, and individualization is difficult. However, this study alerts coaches and researchers that the use of high volume may be detrimental to swimming performance, inclusively when compared with a very short volume stimulus.

ACKNOWLEDGMENTS

The authors would like to acknowledge the help of the swimmers who participated in the present study and also that of the Varzim Lazer EEM in making available the swimming-pool facilities. This work was supported by a grant from the Science and Technology Foundation (SFRH/BD/74950/2010) and by University of Beira Interior and Santander Totta bank (UBI/FCSH/Santander/2010). This research was awarded by COP/Millenium BCP Sport Sciences 2014. The authors have no conflicts of interest that are directly relevant to the content of this study. The results of the present study do not constitute endorsement of the product by the authors or the NSCA.

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