Title: Swimming with swimsuit and wetsuit at typical vs cold-water temperatures (26 vs 18ºC)

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ABSTRACT

The study aimed to compare three swimming conditions in a swimming flume with water at 26°C (using swimsuit) and 18°C (randomly with swimsuit and wetsuit). Seventeen swimmers (32.4±14.7 years old, 175.6±0.06 cm height, and 70.4±9.8 kg body mass) performed the three bouts until exhaustion at 400m front crawl pace (24h intervals). ANOVA repeated measures compared the experimental conditions. Swimming at 26°C with swimsuit evidenced a higher metabolic demand (total energy expenditure; (E)), comparing to 18°C swimsuit (p=0.05) and with 18°C wetsuit (p=0.04). The 26°C swimsuit condition presented higher peak oxygen uptake (\( \dot{V}O_{2\text{peak}} \)), blood lactate concentrations ([La-]_{\text{peak}}), rate of perceived exertion (RPE), maximal heart rate (HR_{\text{max}}), anaerobic lactic energy (AnL), E, energy cost (C), \( \dot{V}O_2 \) amplitude (Ap), and stroke rate (SR), but lower stroke length (SL) and stroke index (SI) than 18°C wetsuit. The 18°C swimsuit condition (comparing to wetsuit) lead to higher \( \dot{V}O_{2\text{peak}} \), [La-]_{\text{peak}}, HR_{\text{max}}, E, C, Ap, and SR but lower SL and SI. Swimming at aerobic power intensity with swim and wetsuit at 18°C
does not induce physiologic and biomechanical disadvantages comparing to 26°C, The
results suggested that the use of wetsuit might increase performance at 18°C water
temperature for competitive master swimmers. Thus, its use is recommended in open
water swimming competitions when the water temperature is 18-20°C.

Key words: Wet suit, Energetics, Biomechanics, Swimming Flume, Open water,
Neoprene.

INTRODUCTION

The use of wetsuit in open water swimming events is very frequent due to the
enhancement in speed compared to the use of swimsuit. The properties of a wetsuit
provoke an increase in buoyancy, leading to a reduction on hydrodynamic drag. It also
induce the increase in propelling efficiency (ηp) resulting in the decrease of the energy
cost of swimming (C) [1,2,3]. In fact, both former and contemporary studies showed a 5
to 7% of performance improvement on 400 m to 30 min swimming events when wearing
a wetsuit [1,4-6], probably due to body drag reduction caused by the buoyancy increment
[1]. However, there is a high variety of wetsuits models (full body, sleeveless long, and
short), some of which are more economic to swim with (presenting lower C values) than
others, related to the body cover [4,7,8].

The use of wetsuits in open water competitions is mandatory, allowed and forbidden
depending on water temperature (lower than 18, from 18 to 20, and higher of 20°C,
respectively) [9]. The reason is to avoid hypothermia in cold-water temperatures [10].
When the immersion in with cold-water lead to the “cold-shock” physiological
phenomenon that is characterized by 1-3 min of hyperventilation and tachycardia
followed by an inspiratory gasp and by a heart rate (HR) decrease due to a blood flow volume reduction [11]. However, these responses are only observed when swimming at temperatures ≤ 15°C and in deep immersions [12,13] but it is not clarified if there are physiologic and biomechanical modifications when swimming with a wetsuit at 18°C. Open water swimming is different compared to pool swimming since there are no turns and wall push-off glide, as the water volume is higher and water temperatures varies, leading to particular cardiovascular and technical responses [14,15]. Therefore, swimming in a flume at different water temperatures could be a good strategy to simulate the typical continuous open water swimming both during training and testing. It was recently observed that performing in a swimming flume and in a 25 m pool is physiological and biomechanically different (independently of the suit used) [6]. In addition, differences in fluid flow characteristics and the changes in their swimming technique during continuous swimming might appear when fatigue occurs [16,17]. Knowing that the 400 m front crawl pace is well related with the velocity that elicits maximal oxygen consumption (\(\dot{V}O_{2\text{max}}\)) and is a valid indicator of aerobic power (one of the most important swimming training zones) in which the anaerobic contribution range between 17 and 40% of the total energy expenditure [18,19], the aim of this study was to compare swimming performed at two water temperatures (18 and 26°C) with and without wetsuits. It was hypothesized that: (i) swimming with a swimsuit at 26 vs 18°C implies lower physiological demands and higher \(\eta_p\); and (ii) swimming at 18°C with swimsuit is less efficient and economic than performing with a wetsuit. Water temperatures of 26 and 18°C were selected since they represent the usual value at indoor swimming pools and the limit under which the use of wetsuit is mandatory in open water swimming competitions [9].
METHODS

Participants

Seventeen competitive master swimmers (15 males and 2 females) voluntarily participated in the current study. Their main physical and performance characteristics were 32.4 ± 14.7 years of age, 175.6 ± 0.06 cm of height, 70.4 ± 9.8 kg of body mass, 181.1 ± 7.1 cm of arm span, 23.03 ± 2.35 kg/m² of body mass index, and 273 ± 130 International Swimming Federation (FINA) points of best competitive performance on 400 m freestyle performance in short-course, with a training time frequency ~8-10 h per week. The Institutional Ethical Review Board approved the study design that has been performed according to the Code of Ethics of the World Medical Association - Declaration of Helsinki (project code: 125/CEIH/2016) and the study follows the ethical standards in sport and exercise science research [20]. A written informed consent was given by all participants.

Experimental Design

After a standard in-water warm up of 1000 m [6] at 26°C, subjects performed three front crawl time-trials in a swimming flume (with 24 h rest in-between) at a water speed simulating each swimmer 400 m front crawl pace (the best time obtained in a 400 m freestyle competition). The distance selected was assumed to be an aerobic power pace [18,19]. Due to specific constraints to cool down the water, subjects firstly swam at 26°C using a swimsuit and, after the water temperature was decreased to 18°C, they randomly and counterbalanced perform the trials with a personal swimsuit and wetsuit (2.24 ± 0.89, 2.87 ± 1.18, and 2.64 ± 1.07 mm of upper limbs trunk and lower limbs thickness accordingly to FINA rules). In the three conditions swimmers were asked to stay at the
center of the swimming flume and to continue swimming until they were not able to keep
the pace. Swimmers had previous experience in flume swimming, using a breathing
snorkel and a nose clip, and abstained to take stimulant drinks and practice exhaustive
exercise 48 h prior to the trials. The trials were conducted at the same time of day (at a
room with 24 ± 1.5°C air temperature and 51 ± 2.7% relative air humidity) and prior 24
h nutrition was controlled.

Methodology
Experimental trials were conducted in a 2.4 x 4.7 m Endless Pool (Elite Techno Jet Swim
7.5 HP, Aston PA, USA), with its flow speed measured at 0.30 cm depth using an FP101
flow probe device (Global Water, Gold River, CA) [21]. A K4b2 (Cosmed, Rome, Italy)
breath-by-breath portable gas analyzer which allows the direct measurement of
respiratory and pulmonary gas exchange variables, being suspended at 1.8 m above the
water surface (Figure 1). The gas analyzer was attached to a low hydrodynamic resistance
respiratory snorkel and valve system (Aquatrainer, Cosmed, Rome, Italy) [14,22] and was
calibrated with 16% O2 and 5% CO2 concentration gases before each testing session. HR
was measured using telemetry (Polar Wearlink, Kempele, Finlandia) synchronized with
the portable gas analyzer. A surface and underwater cameras (Nikon Corporation, Japan
and Panasonic Full-HD HX-A500, Osaka, Japan), operating at 50 Hz and placed on the
swimming flume frontal and sagittal plans (respectively), were used to assess the
biomechanical variables (see below). A pre-calibrated space was used as a reference for
video analysis with one meter wide and 14 points used for calibrations, situated in the
center of the swimming flume [6].

Insert Figure 1
Data Analysis

VO₂ data was analyzed using the VO₂FITTING open and free software [23], with a mono-exponential model adjusting the best profile for the three experimental conditions (equation 1):

\[ \dot{V}O_2(t) = A_0 + H(t - TD_p) \cdot A_p (1 - e^{-(t-TD_p)/\tau_p}) \]  (1)

where \( \dot{V}O_2 \) (t) represents the relative \( \dot{V}O_2 \) at the time t, \( A_0 \) is the rest \( \dot{V}O_2 \) (the pre-exercise last 2 min average), H represents the Heaviside step function and \( A_p, TD_p \) and \( \tau_p \) are the fast \( \dot{V}O_2 \) component amplitude, time delay and time constant (respectively) [23]. \( \dot{V}O_2 \) values included only those between \( \dot{V}O_2 \pm 4 \) SD, decreasing the noise between breaths caused when swimmers swallow water, cough or the signal is interrupted [24]. Then, individual breath-by-breath \( \dot{V}O_2 \) responses were smoothed using a three-breath moving average and time averaged every 10 s [23,24] allowing the highest incidence of \( \dot{V}O_2 \) plateau occurrence regardless the distance performed [24]. Peak oxygen consumption (\( \dot{V}O_{2\text{peak}} \)) and other physiological variables, as maximal heart rate (HR\text{max}) and respiratory exchange ratio (RER), were obtained from the last 30 s of each trial.

The total energy expenditure (E) was estimated as the sum of aerobic (Aer), anaerobic lactic (AnL) and anaerobic alactic (AnAL) energy contributions, with the first two calculated, respectively, from the time integral of the net \( \dot{V}O_2 \) vs time relationship and using the following equation [25,26]:

\[ \text{AnL} = ([La^-]_{\text{net}} \cdot \beta \cdot M) \]  (2)

where \( [La^-]_{\text{net}} \) is the difference between the blood lactate concentration ([La\(^{-1}\)]) before and after exercise ([La\(^{-}\text{peak}\)], \( \beta \) is the constant for O\(_2\) equivalent of \( [La^-]_{\text{net}} \) (2.7 mL \cdot kg \cdot min\(^{-1}\)) \(^{1}\) and M is the swimmer body mass in kilograms. Afterwards, these energy contributions were expressed in kJ assuming an energy equivalent of 20.9 kJ \cdot L\(^{-1}\) [19]. The AnAL was
estimated from the maximal phosphocreatine splitting in the contracting muscle, using this equation [25]:

$$AnAL = PCr \cdot (1 - e^{-t/\tau}) \cdot M$$  \hspace{1cm} (3)$$

where $PCr$ is the rest phosphocreatine concentration, $t$ is the exercise time, $\tau$ is the $PCr$ splitting time constant at exercise onset (23.4 s) and $M$ is the body mass. Then, $AnAL$ was expressed in kJ by assuming an energy equivalent of 0.468 kJ $\cdot$ mM and a phosphate/oxygen ratio of 6.25 [27]. $C$ was obtained as the ratio between $E$ and distance swam at 400 m front crawl pace [28]. Capillary blood samples (25 $\mu$L) were collected from the fingertip immediately after each trial (and at the 1, 3, 5 and 7 min of the recovery period) using a portable lactate analyzer (Lactate Pro analyzer, Arkray, Inc., Kyoto, Japan) to assess $[La-]_{peak}$ [6,29]. In addition, immediately after each trial, swimmers rated their perceived exertion (RPE) on a Borg scale [24].

Stroke rate (SR) was obtained measuring three consecutive upper limbs cycles, stroke length (SL) was calculated from the ratio between $v$ and corresponding SR [14] and stroke index (SI), a measure of swimming efficiency, was calculated by multiplying $v$ by SL [19]. Finally, $\eta_p$ was estimated as follow [30]:

$$\eta_p = [(v \cdot 0.9 / 2\pi \cdot SR \cdot l) \cdot 2/\pi] \cdot 100$$  \hspace{1cm} (4)$$

where $l$ is the distance between the shoulder and wrist during the insweep (with the hand situated exactly under the shoulder) Reference points were drawn at the shoulders, hips and wrists to allow a proper biomechanical analysis. The distance between the points were calculated with 2D motion analysis software Kinovea (version 0.8.15). For both upper limbs due to a mirror was use to digitalize the upper limb of the left side of the swimming flume.

Statistical Analysis

8
IBM SPSS Statistics (version 20, IBM SPSS, Chicago, USA) was used to data analysis, with Shapiro-Wilk confirming its normality and homogeneity. ANOVA repeated measures was computed to compare the three experimental conditions. Sphericity was verified by means of the Mauchly test and adjusted according to the Greenhouse-Geisser procedure when the significance of the F-ratios were not met. Bonferroni post hoc was performed to locate the pairwise differences between the means (p < 0.05) with 95% of confidence interval (CI). The Cohen’s $d$ effect was calculated (0 to 0.19 trivial, 0.2 to 0.59 small, 0.6 to 1.99 moderate, 1.2 to 1.99 large, 2.0 to 3.9 very large and > 4.0 nearly perfect) [6]. The relationships between the time endured in the different trials and the corresponding energetic contributions were assessed with Pearson’s correlations coefficients ($r$) and linear regression analysis.

**RESULTS**

Comparisons between experimental conditions conducted at different temperatures and swimming suits at the 400 m front crawl pace are presented in Table 1. Bonferroni post hoc analysis showed that $E$ was different between the three comparisons. Nevertheless, $\text{VO}_{2\text{peak}}$, $HR_{\text{max}}$, $[\text{La-}]_{\text{peak}}$, C, Ap, SR, SL, and SI were different in between 26 swimsuit and 18ºC swimsuit and between 18 swimsuit and 18ºC wetsuit conditions (Table 2). In Table 1 it could be observed the percentual contribution of each energy system for the overall swimming performance at each water temperature and suit condition. However, only the AnL contribution showed differences between 26 swimsuit and 18ºC wetsuit conditions (Table 2). Complementarily, in the 26ºC swimsuit condition, the time endured at the aerobic power pace was directly related with Aer ($r = 0.69$; $p < 0.001$; Figure 2, panel C) and inversely related with AnAL ($r = -0.62$; $p < 0.001$; Figure 2, panel A). No
statistically relationships were observed between swimming performance and energetic
ccontributions in the two other studied conditions (18ºC swimsuit and 18ºC wetsuit) as it
is shown in Figure 2.

Insert Table 1
Insert Table 2
Insert Figure 2

DISCUSSION
The main aim of the current study was to assess relevant physiological and biomechanical
variables while swimming to exhaustion at each individual 400 m front crawl pace (i.e.,
at the aerobic power intensity) using swim and wetsuits at typical and cold-water
temperatures. Contrary to our expectation, swimming with a swimsuit at 18ºC did not
increase swimmers physiological demands (even enduring 20-25 s longer) compared to
performing at representative swimming pool water temperature (26ºC). Additionally, as
anticipated, swimming at 18ºC with swimsuit was less economic than with wetsuit (and
lower physiological variables values and better technical characteristics were observed in
this latter condition) accordingly with previous reports of better performances when
wearing wetsuits [1,4,6].

As referred before, using a wetsuit at open water competitions with 18ºC water
temperature is optional [9]. It is known that subjects submerged in cold-water suffer a
cold-shock response that might lead to vasoconstriction and blood flow reduction [11],
particularly when using regular swimsuits that do not give any relevant protection against
low water temperatures. However, only RPE and E showed differences between the 26
and 18ºC swimsuit conditions. The reason might be that this water temperature was not
sufficient to cause significant cold-shock responses and/or the exposure time was enough to reduce the metabolic responses of cold water (which is studied to be subsided after the first 5 min of immersion time [31]) and in the current study, the maximum time swam at 18°C water temperature was ~6.40 min. Still, when using a wetsuit at 18°C, an evident decrease of the cardiorespiratory and technical variables was found, evidencing that this condition required lower E and C values compared to 18°C swimsuit as it can be observed in Table 2 (p = 0.04; d = 0.67 and p = 0.04; d = 0.68, respectively) (i.e., it was more economic than swimming with a swimsuit both at 26 and 18°C).

Regarding oxygen kinetics at the primary cardiorespiratory response, it was observed that \( \tau_p > 20 \) s (as reported before [32]), with no differences between the three experimental conditions. TDp also was similar between conditions, with values ~10-20 s. However, the higher Ap values for the conditions 26°C swimsuit vs 18°C wetsuit and 18°C swimsuit vs 18°C wetsuit might indicate that the Aer contribution was accentuated by cold water and wetsuit use. In addition, the AnL contributions were higher at 26 compared to 18°C wetsuit, in accordance with the [La-]_peak values, an indicator of anaerobic energy requirement [27]. This, plus the use of wetsuit in the cooler condition, might justify why swimmers were able to maintain the time endured in all experimental conditions. When swimming at 18°C without wetsuit, swimmers maintained the pace eventually due to the cold-shock response that lead to higher HR\(_{max}\) values [11].

In fact, when wearing a wetsuit, swimmers lower limbs sinking torque is less expressive, decreasing their hydrodynamic drag and, consequently, the C for the same speed [33]. This was observed in the current study with a SL and SI increment (and a SR decrease) at the 18°C wetsuit condition even if usually the wetsuit thickness limits the shoulder range of motion leading to a SR increase [34]. This is in line with previously reported data when using a wetsuit comparing to swimsuit in a flume at the aerobic power intensity.
As time to exhaustion at $\dot{V}\text{O}_{2\text{max}}$ is directly influenced by C, SL and SI [17,18,33], the lower values in time endured at 26°C swimsuit seems to express that swimmers experienced it as the most difficult metabolic and technical condition. This can be observed by the higher RPE, $[\text{La}^-]_{\text{peak}}$, $\dot{V}\text{O}_{2\text{max}}$, and SR values (also with higher values of power), although the learning effect might also influenced the results since the warmer condition was performed first.

In accordance with these data, a swimming efficiency rise at the 18°C wetsuit exertion was expected. However, when comparing the $\eta_p$ at the different conditions, the p value although very close to 0.05 fell short of statistical meaning (with lower $\eta_p$ and power). This might be justified by methodological constraints, particularly by the fact that the $\eta_p$ calculation was limited to the SR, neither considering technical aspects responsible for propulsion nor thrust-producing vortices. Complementarily, the lower values of $l$ might have induced higher efficiency values [30], for which the swimming ability is an important factor. Eventually, if another $\eta_p$ assessment method was used (e.g., by assessing the ratio of the speed of the center of mass to three dimensional speed of the right and left upper limbs during underwater phase [29]) the results might be different.

It is also important to highlight that, even if a swimming flume allows to better set and control the swimmers pace, it has some specificities that might influence both physiological and biomechanical variables. In fact, the hydrodynamic resistance that swimmers need to overcome is different from free swimming due to its non-laminar water flow, consequently influencing swimmers technique and E [6,16]. The higher the water temperature, the lower the water density and, consequently, the lower the hydrodynamic resistance [35]. However, at higher temperatures the body temperature increases, and more energy requirement might be necessary for self-regulation, probably explaining the higher energetics requirement values at the 26°C condition.
Furthermore, flume swimming does not include the start and turn phases, which might also influence swimmers comparing to swimming in a pool. However, these swimmers participate in open water and triathlon competitions hence, swimming in a flume might replicate real swimming events. In addition, though our swimmers had considerable experience using the swimming flume and the breathing snorkel, we could accept that their technique might be affected and, in consequence, their energy requirements could be different from swimming unimpeded in a pool, but as the aim of the study is related to open water, the used of a swimming flume could be a more ecologically valid method to measure continuous swimming than swimming pool. In conclusion, when using a wetsuit at 18ºC, an evident decrease of the cardiorespiratory and technical variables was found, demonstrating that this condition require lower E and C values. Thus, it was more economic than swimming with a swimsuit both at 26 and 18ºC. The results suggested that the use of wetsuit might increase performance at 18ºC water temperature for competitive master swimmers.

**PRACTICAL APPLICATIONS**

In the current study it was underscored the importance of the use of wetsuit at 18ºC for open water swimming competitions since it allows a better technique and effort economy (comparing to wearing a swimsuit), meaning that for the same energy input its use will allow better performances. Also, since the anaerobic threshold pace happens at ~90% of the 400 m intensity [18,19], the physiologic and biomechanical variables values displayed in our study could be useful for evaluating the open water swimmers and triathletes performance that typically happens below or at that boundary [14,15]. Notwithstanding the swimming flume particularities (that should be considered when analysing data), its
use makes the process of evaluating swimmers easier both at the physiologic and biomechanical areas, reason why swimmers in general (and open water specialists in particular) should use it on a regular basis to follow-up their training process.

CONFLICT OF INTEREST

Authors have no conflict of interest to report.

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<table>
<thead>
<tr>
<th>Variable</th>
<th>26°C swimsuit</th>
<th>18°C swimsuit</th>
<th>18°C wetsuit</th>
<th>F</th>
<th>P</th>
<th>Eta^2</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Time endured (s)</strong></td>
<td>304.9 ± 78.38</td>
<td>330.8 ± 52.97</td>
<td>334.1 ± 52.13</td>
<td>1.58</td>
<td>0.22</td>
<td>0.09</td>
<td>0.31</td>
</tr>
<tr>
<td><em>v</em> (m·s⁻¹)</td>
<td>1.23 ± 0.21</td>
<td>1.23 ± 0.17</td>
<td>1.24 ± 0.21</td>
<td>0.44</td>
<td>0.55</td>
<td>0.03</td>
<td>0.10</td>
</tr>
<tr>
<td><strong>VO₂peak</strong> (mL·kg⁻¹·min⁻¹)</td>
<td>47.7 ± 11.80†</td>
<td>44.7 ± 8.40‡</td>
<td>39.10 ± 8.30‡</td>
<td>12.64</td>
<td>0.00</td>
<td>0.44</td>
<td>0.99</td>
</tr>
<tr>
<td><strong>VE</strong> (l·min⁻¹)</td>
<td>129.60 ± 31.10†</td>
<td>119.70 ± 32.70</td>
<td>101.00 ± 26.70†</td>
<td>9.08</td>
<td>0.00</td>
<td>0.36</td>
<td>0.96</td>
</tr>
<tr>
<td><strong>ΔVE</strong> (l·min⁻¹)</td>
<td>125.80 ± 30.60‡</td>
<td>114.90 ± 33.40‡</td>
<td>95.10 ± 27.40‡</td>
<td>10.72</td>
<td>0.00</td>
<td>0.40</td>
<td>0.98</td>
</tr>
<tr>
<td><strong>[La]basal</strong> (mmol·l⁻¹)</td>
<td>2.25 ± 0.78‡</td>
<td>2.22 ± 1.08†</td>
<td>2.18 ± 1.14†</td>
<td>0.04</td>
<td>0.97</td>
<td>0.00</td>
<td>0.05</td>
</tr>
<tr>
<td><strong>[La]peak</strong> (mmol·l⁻¹)</td>
<td>10.25 ± 3.45†</td>
<td>7.99 ± 4.38‡</td>
<td>5.21 ± 2.65‡</td>
<td>14.36</td>
<td>0.00</td>
<td>0.47</td>
<td>1.00</td>
</tr>
<tr>
<td><strong>Δ[La]</strong> (mmol·l⁻¹)</td>
<td>8.00 ± 3.53†</td>
<td>5.77 ± 4.39‡</td>
<td>3.03 ± 2.68‡</td>
<td>12.57</td>
<td>0.00</td>
<td>0.49</td>
<td>0.99</td>
</tr>
<tr>
<td><strong>RPE</strong></td>
<td>7.12 ± 1.32†</td>
<td>5.35 ± 1.73‡</td>
<td>6.00 ± 2.09‡</td>
<td>9.38</td>
<td>0.00</td>
<td>0.37</td>
<td>0.97</td>
</tr>
<tr>
<td><strong>HRmax</strong> (beats·min⁻¹)</td>
<td>181.88 ± 19.24†</td>
<td>182.88 ± 18.79β</td>
<td>154.18 ± 12.08β</td>
<td>15.98</td>
<td>0.00</td>
<td>0.50</td>
<td>0.99</td>
</tr>
<tr>
<td><strong>ΔHR</strong> (beats·min⁻¹)</td>
<td>105.47 ± 18.39†</td>
<td>109.76 ± 21.71β</td>
<td>74.12 ± 15.14β</td>
<td>21.32</td>
<td>0.00</td>
<td>0.57</td>
<td>1.00</td>
</tr>
<tr>
<td><strong>RF</strong> (breaths·min⁻¹)</td>
<td>57.98 ± 19.27†</td>
<td>51.61 ± 13.92β</td>
<td>51.43 ± 15.76β</td>
<td>2.12</td>
<td>0.14</td>
<td>0.12</td>
<td>0.40</td>
</tr>
<tr>
<td><strong>ΔRF</strong> (breaths·min⁻¹)</td>
<td>50.63 ± 19.90†</td>
<td>43.33 ± 14.36β</td>
<td>41.43 ± 16.12β</td>
<td>3.70</td>
<td>0.04</td>
<td>0.19</td>
<td>0.64</td>
</tr>
<tr>
<td><strong>RER</strong></td>
<td>1.20 ± 0.20†</td>
<td>1.30 ± 0.30†</td>
<td>1.20 ± 0.30†</td>
<td>0.69</td>
<td>0.51</td>
<td>0.04</td>
<td>0.16</td>
</tr>
<tr>
<td><strong>ΔRER</strong></td>
<td>0.50 ± 0.20†</td>
<td>0.40 ± 0.30†</td>
<td>0.40 ± 0.30†</td>
<td>2.34</td>
<td>0.11</td>
<td>0.13</td>
<td>0.44</td>
</tr>
<tr>
<td><strong>AnAL</strong> (kJ)</td>
<td>29.25 ± 4.08†</td>
<td>29.25 ± 4.09†</td>
<td>29.25 ± 4.09†</td>
<td>1.72</td>
<td>0.20</td>
<td>0.10</td>
<td>0.24</td>
</tr>
<tr>
<td><strong>AnL</strong> (kJ)</td>
<td>31.72 ± 14.73†</td>
<td>23.06 ± 18.78β</td>
<td>12.18 ± 11.01†</td>
<td>12.99</td>
<td>0.00</td>
<td>0.45</td>
<td>0.99</td>
</tr>
<tr>
<td><strong>Aer</strong> (kJ)</td>
<td>309.47 ± 97.08</td>
<td>314.02 ± 66.20</td>
<td>273.59 ± 57.60</td>
<td>2.43</td>
<td>0.10</td>
<td>0.13</td>
<td>0.45</td>
</tr>
<tr>
<td><strong>AnAL</strong> (%)</td>
<td>8.69 ± 3.38†</td>
<td>8.20 ± 1.48†</td>
<td>9.60 ± 2.43†</td>
<td>1.98</td>
<td>0.16</td>
<td>0.11</td>
<td>0.38</td>
</tr>
<tr>
<td><strong>AnL</strong> (%)</td>
<td>8.60 ± 3.54†</td>
<td>6.15 ± 4.15†</td>
<td>3.88 ± 3.34‡</td>
<td>12.20</td>
<td>0.00</td>
<td>0.43</td>
<td>0.99</td>
</tr>
<tr>
<td><strong>Aer</strong> (%)</td>
<td>82.72 ± 5.38†</td>
<td>85.65 ± 4.36β</td>
<td>86.52 ± 4.63β</td>
<td>4.23</td>
<td>0.02</td>
<td>0.21</td>
<td>0.70</td>
</tr>
<tr>
<td><strong>E</strong> (kJ)</td>
<td>370.44 ± 105.88†</td>
<td>366.34 ± 74.16**β</td>
<td>315.02 ± 60.71†β</td>
<td>4.20</td>
<td>0.02</td>
<td>0.21</td>
<td>0.70</td>
</tr>
<tr>
<td><strong>C</strong> (kJ·m⁻¹)</td>
<td>0.93 ± 0.26†</td>
<td>0.92 ± 0.19β</td>
<td>0.79 ± 0.15†</td>
<td>4.20</td>
<td>0.02</td>
<td>0.21</td>
<td>0.70</td>
</tr>
<tr>
<td><strong>Ap</strong> (ml·kg⁻¹·min⁻¹)</td>
<td>42.40 ± 12.30†</td>
<td>37.00 ± 5.90β</td>
<td>32.20 ± 6.80†</td>
<td>15.87</td>
<td>0.00</td>
<td>0.50</td>
<td>0.99</td>
</tr>
<tr>
<td><strong>TDp</strong> (s)</td>
<td>18.98 ± 8.35</td>
<td>18.02 ± 6.90</td>
<td>16.44 ± 0.79</td>
<td>0.70</td>
<td>0.51</td>
<td>0.04</td>
<td>0.16</td>
</tr>
<tr>
<td><strong>Tp</strong> (s)</td>
<td>25.20 ± 12.17</td>
<td>26.21 ± 17.60</td>
<td>23.55 ± 15.46</td>
<td>0.18</td>
<td>0.83</td>
<td>0.01</td>
<td>0.08</td>
</tr>
<tr>
<td><strong>SR</strong> (Hz)</td>
<td>0.56 ± 0.08†</td>
<td>0.55 ± 0.07β</td>
<td>0.51 ± 0.07†β</td>
<td>19.99</td>
<td>0.00</td>
<td>0.56</td>
<td>1.00</td>
</tr>
<tr>
<td><strong>SL</strong> (m)</td>
<td>2.25 ± 0.43†</td>
<td>2.28 ± 0.38β</td>
<td>2.48 ± 0.48†β</td>
<td>16.81</td>
<td>0.00</td>
<td>0.51</td>
<td>1.00</td>
</tr>
<tr>
<td><strong>SI</strong> (m²·s⁻¹)</td>
<td>2.83 ± 1.04†</td>
<td>2.86 ± 0.84β</td>
<td>3.15 ± 1.17†β</td>
<td>8.45</td>
<td>0.00</td>
<td>0.35</td>
<td>0.95</td>
</tr>
<tr>
<td><strong>nP</strong> (%)</td>
<td>46.55 ± 8.96</td>
<td>45.90 ± 8.35</td>
<td>48.90 ± 10.93</td>
<td>3.16</td>
<td>0.06</td>
<td>0.16</td>
<td>0.56</td>
</tr>
</tbody>
</table>

Swimming speed (*v*), maximal oxygen consumption (**VO₂peak**) ventilation (**VE**), delta ventilation (**ΔVE**), basal blood lactate concentrations (**[La]basal**), peak blood lactate concentrations (**[La]peak**), delta blood lactate concentrations (**Δ[La]**), Borg rating of perceived exertion scale (**RPE**), maximal heart rate (**HRmax**), delta heart rate (**ΔHR**), respiratory frequency (**RF**), delta respiratory frequency (**ΔRF**), respiratory exchange ratio (**RER**), delta respiratory exchange ratio (**ΔRER**), anaerobic alactic, anaerobic lactic and aerobic contributions (**AnAL, AnL and Aer**), total energy expenditure (**E**), energy cost (**C**), amplitude, time delay and tau of the oxygen consumption (**Ap, TDP and Tp**), stroke rate, length and index (**SR, SL and SI**) and propelling efficiency (**nP**). *†‡** Differences between 26 vs 18°C swimsuit, 25°C swimsuit vs 18°C wetsuit and 18°C swimsuit vs wetsuit.
<table>
<thead>
<tr>
<th>Variable</th>
<th>Difference [95%CI]; %Δ</th>
<th>p</th>
<th>Effect size (d)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>26 swimsuit vs 18°C swimsuit</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RPE</td>
<td>1.76 [0.81, 2.72]; -24.79%</td>
<td>0.000</td>
<td>1.16, Moderate</td>
</tr>
<tr>
<td>E (kJ)</td>
<td>4.11 [-59.93, 68.14]; -1.11%</td>
<td>0.050</td>
<td>0.04, Trivial</td>
</tr>
<tr>
<td><strong>26 swimsuit vs 18°C wetsuit</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VO\textsubscript{peak} (mL·kg\textsuperscript{-1}·min\textsuperscript{-1})</td>
<td>8.62 [3.86, 13.39]; -18.07%</td>
<td>0.001</td>
<td>1.17, Moderate</td>
</tr>
<tr>
<td>VE (l/min)</td>
<td>28.57 [11.41, 45.73]; -22.05%</td>
<td>0.001</td>
<td>1.08, Moderate</td>
</tr>
<tr>
<td>(\Delta\text{VE} ) (l/min)</td>
<td>30.71 [14.05, 47.36]; -24.41%</td>
<td>0.000</td>
<td>1.20, Large</td>
</tr>
<tr>
<td>[La\textsubscript{peak}] (mmol·l\textsuperscript{-1})</td>
<td>5.04 [3.09, 6.99]; -49.2%</td>
<td>0.000</td>
<td>1.68, Large</td>
</tr>
<tr>
<td>(\Delta[\text{La}] ) (mmol·l\textsuperscript{-1})</td>
<td>4.97 [2.93, 7.02]; -62.13%</td>
<td>0.000</td>
<td>1.58, Large</td>
</tr>
<tr>
<td>RPE</td>
<td>1.12 [0.02, 2.21]; -15.7%</td>
<td>0.045</td>
<td>0.66, Moderate</td>
</tr>
<tr>
<td>HR\textsubscript{peak} (beats·min\textsuperscript{-1})</td>
<td>27.70 [14.60, 40.81]; -15.23%</td>
<td>0.000</td>
<td>1.37, Large</td>
</tr>
<tr>
<td>(\Delta\text{HR} ) (beats·min\textsuperscript{-1})</td>
<td>31.35 [16.95, 45.75]; -29.72%</td>
<td>0.000</td>
<td>1.41, Large</td>
</tr>
<tr>
<td>(\Delta\text{RF} ) (breaths·min\textsuperscript{-1})</td>
<td>9.2 [-0.26, 18.65]; -18.17%</td>
<td>0.050</td>
<td>0.63, Moderate</td>
</tr>
<tr>
<td>AnL (kJ)</td>
<td>19.54 [11.56, 27.52]; -61.6%</td>
<td>0.000</td>
<td>1.59, Large</td>
</tr>
<tr>
<td>AnL (%)</td>
<td>4.72 [2.24, 7.19]; -54.87%</td>
<td>0.000</td>
<td>1.24, Large</td>
</tr>
<tr>
<td>E (kJ)</td>
<td>55.42 [-1.25, 112.09]; -14.96%</td>
<td>0.050</td>
<td>0.63, Moderate</td>
</tr>
<tr>
<td>C (kJ·m\textsuperscript{-1})</td>
<td>0.14 [0, 0.28]; -14.96%</td>
<td>0.050</td>
<td>0.63, Moderate</td>
</tr>
<tr>
<td>Ap (ml·kg\textsuperscript{-1}·min\textsuperscript{-1})</td>
<td>10.1 [4.98, 15.23]; -23.86%</td>
<td>0.000</td>
<td>1.28, Large</td>
</tr>
<tr>
<td>SR (Hz)</td>
<td>0.05 [0.02, 0.08]; -8.68%</td>
<td>0.001</td>
<td>1.21, Large</td>
</tr>
<tr>
<td>SL (m)</td>
<td>-0.23 [-0.37, -0.1]; 10.39%</td>
<td>0.001</td>
<td>-1.11, Moderate</td>
</tr>
<tr>
<td>SI (m\textsuperscript{2}·s\textsuperscript{-1})</td>
<td>-0.32 [-0.51, -0.14]; 11.33%</td>
<td>0.001</td>
<td>-1.11, Moderate</td>
</tr>
<tr>
<td><strong>18 swimsuit vs 18°C wetsuit</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VO\textsubscript{peak} (mL·kg\textsuperscript{-1}·min\textsuperscript{-1})</td>
<td>5.62 [1.22, 10.03]; -12.57%</td>
<td>0.011</td>
<td>0.83, Moderate</td>
</tr>
<tr>
<td>(\Delta\text{VE} ) (l/min)</td>
<td>19.8 [0.44, 39.17]; -17.24%</td>
<td>0.044</td>
<td>0.66, Moderate</td>
</tr>
<tr>
<td>[La\textsubscript{peak}] (mmol·l\textsuperscript{-1})</td>
<td>2.79 [0.15, 5.43]; -34.88%</td>
<td>0.037</td>
<td>0.69, Moderate</td>
</tr>
<tr>
<td>HR\textsubscript{peak} (beats·min\textsuperscript{-1})</td>
<td>28.70 [11.24, 46.18]; -15.69%</td>
<td>0.001</td>
<td>1.07, Moderate</td>
</tr>
<tr>
<td>(\Delta\text{HR} ) (beats·min\textsuperscript{-1})</td>
<td>35.64 [18.24, 53.06]; -32.47%</td>
<td>0.000</td>
<td>1.33, Large</td>
</tr>
<tr>
<td>E (kJ)</td>
<td>51.31 [2.02, 100.6]; -14.01%</td>
<td>0.040</td>
<td>0.67, Moderate</td>
</tr>
<tr>
<td>C (kJ·m\textsuperscript{-1})</td>
<td>0.13 [0.01, 0.25]; -14.01%</td>
<td>0.040</td>
<td>0.68, Moderate</td>
</tr>
<tr>
<td>Ap (ml·kg\textsuperscript{-1}·min\textsuperscript{-1})</td>
<td>4.76 [2.09, 7.43]; -12.86%</td>
<td>0.001</td>
<td>1.16, Moderate</td>
</tr>
<tr>
<td>SR (Hz)</td>
<td>0.04 [0.02, 0.05]; -6.83%</td>
<td>0.000</td>
<td>1.86, Large</td>
</tr>
<tr>
<td>SL (m)</td>
<td>-0.2 [-0.31, -0.09]; 8.59%</td>
<td>0.001</td>
<td>-1.15, Moderate</td>
</tr>
<tr>
<td>SI (m\textsuperscript{2}·s\textsuperscript{-1})</td>
<td>-0.3 [-0.57, -0.02]; 10.34%</td>
<td>0.034</td>
<td>-0.70, Moderate</td>
</tr>
</tbody>
</table>

Borg rating of perceived exertion scale (RPE), total energy expenditure (E), Maximal oxygen consumption (\(\text{VO}_\text{peak}\)), ventilation (VE), delta ventilation (\(\Delta\text{VE}\)), peak blood lactate concentrations ([La\textsubscript{peak}], delta blood lactate concentrations (\(\Delta[\text{La}]\)), maximal heart rate (HR\textsubscript{peak}), delta heart rate (\(\Delta\text{HR}\)), delta respiratory frequency (\(\Delta\text{RF}\)), anaerobic lactic contribution (AnL), energy cost (C), amplitude of the oxygen consumption (Ap), stroke rate, length, and index (SR, SL and SI).

pairwise comparisons (n = 17).
**Figure 1.** Graphic representation of the swimming flume. A: space for the swimmer; B: water channel; C: flume monitor where it was selected the swimming speed; D: mobile structure attached to the apparatus; E: K4b$^2$ and respiratory snorkel Aquatrainer; F: underwater sagittal camera; and G: surface front camera. Dashed arrows represent the water flow direction.
Figure 2. Relationships between the times endured on 400 m front crawl (at 26 and 18°C with swimsuit and at 18°C with wetsuit) with the energetic contribution percentages. Anaerobic alactic energy (AnAL; panels A, D, and G); Anaerobic lactic energy (AnL; panels B, E, and H) and; Aerobic energy (Aer; panels C, F, and I). Individual values (continuous lines) and 95% confidence intervals (dashed lines) are represented (n = 17).