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

Full Names of the Authors and Institutional/Corporate Affiliations:

Ana Gay[1]

Rodrigo Zacca[2,3,4]

J. Arturo Abraldes[5]

Esther Morales[1]

Gracia López-Contreras[1]

Ricardo J. Fernandes[2,3]

Raúl Arellano[1]

[1]Aquatics Lab, Department of Physical Education and Sports, Faculty of Sport Sciences, University of Granada, Granada, Spain.

[2]Centre of Research, Education, Innovation and Intervention in Sport (CIFI2D), Faculty of Sport, University of Porto, Porto, Portugal

[3]Porto Biomechanics Laboratory (LABIOMEP), Faculty of Sport, University of Porto, Porto, Portugal.

[5]Research Group Movement, Science and Sport, Faculty of Sport Science, University of Murcia, Spain.

Contact Details for the Corresponding Author:

Ricardo J. Fernandes
Centre of Research, Education, Innovation and Intervention in Sport (CIFI2D), Faculty of Sport, University of Porto, Porto, Portugal.
Porto Biomechanics Laboratory (LABIOMEP-UP), University of Porto, Porto, Portugal.
R. Dr. Plácido da Costa 91, 4200-450, Porto, Portugal.
Phone: +351 220425273
Email: ricfer@fade.up.pt

ABSTRACT

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

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 20ºC, 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 ≤ 15ºC and in deep immersions [12,13] but it is not clarified if there are physiologic and biomechanical modifications when swimming with a wetsuit at 18ºC.

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 ($\dot{V}O_{2max}$) 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 26ºC) with and without wetsuits. It was hypothesized that: (i) swimming with a swimsuit at 26 vs 18ºC implies lower physiological demands and higher ηp; and (ii) swimming at 18ºC with swimsuit is less efficient and economic than performing with a wetsuit.. Water temperatures of 26 and 18ºC 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/m^2 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 26ºC, 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 26ºC using a swimsuit and, after the water temperature was decreased to 18ºC, 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 ± 1.5ºC 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 K4b^2 (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% O_2 and 5% CO_2 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

$\dot{V}\mathbf{O_2}$ data was analyzed using the VO_2FITTING open and free software [23], with a mono-exponential model adjusting the best profile for the three experimental conditions (equation 1):

$$\dot{V}\mathbf{O_2}(\boldsymbol{t}) = \boldsymbol{A_0} + \boldsymbol{H}\left(\boldsymbol{t} - \boldsymbol{TD_p}\right)\cdot\ \boldsymbol{A_P}(\mathbf{1} - \boldsymbol{e}^{-(\boldsymbol{t}-\mathbf{TD}_{\boldsymbol{p}})/\boldsymbol{\tau_p}}) \quad (1)$$

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 Ap, TDp and τ_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 ($\dot{V}O_{2peak}$) and other physiological variables, as maximal heart rate (HR_{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]:

$$\mathbf{AnL} = [\mathbf{La}^{-}]_{\mathbf{net}} \cdot \boldsymbol{\beta} \cdot \mathbf{M} \qquad (2)$$

where $[La^-]_{net}$ is the difference between the blood lactate concentration ($[La^-]$) before and after exercise ($[La\text{-}]_{peak}$), β is the constant for O_2 equivalent of $[La^-]_{net}$ (2.7 ml · kg · min^{-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 · L^{-1} [19]. The AnAL was estimated from the maximal phosphocreatine splitting in the contracting muscle, using this equation [25]:

$$\mathbf{AnAL} = \mathbf{PCr} \cdot (\mathbf{1} - \boldsymbol{e}^{-t/\tau}) \cdot \mathbf{M} \qquad (3)$$

where PCr is the rest phosphocreatine concentration, t is the exercise time, τ 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 · 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 μL) 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 $[La\text{-}]_{peak}$ [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, ηp was estimated as follow [30]:

$$\eta_p = [(v \cdot 0.9 / 2\pi \cdot SR \cdot l) \cdot 2/\pi] \cdot 100 \qquad (4)$$

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

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 1.19 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, $\dot{V}O_{2peak}$, $HR_{max,}$ $[La\text{-}]_{peak}$, 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 contributions 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 18ºC water temperature was ~6.40 min. Still, when using a wetsuit at 18ºC, an evident decrease of the cardiorespiratory and technical variables was found, evidencing that this condition required lower E and C values compared to 18º 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 18ºC).

Regarding oxygen kinetics at the primary cardiorespiratory response, it was observed that τ_p was > 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 26ºC swimsuit vs 18ºC wetsuit and 18ºC swimsuit vs 18ºC 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 18ºC 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 18ºC 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 18ºC 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

[6]. As time to exhaustion at $\dot{V}O_{2max}$ is directly influenced by C, SL and SI [17,18,33], the lower values in time endured at 26ºC swimsuit seems to express that swimmers experienced it as the most difficult metabolic and technical condition. This can be observed by the higher RPE, $[La\text{-}]_{peak}$, $\dot{V}O_{2max}$, 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 18ºC wetsuit exertion was expected. However, when comparing the ηp at the different conditions, the p value although very close to 0.05 fell short of statistical meaning (with lower eta^2 and power). This might be justified by methodological constraints, particularly by the fact that the ηp 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 ηp 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 26ºC condition.

Furthermore, flume swimming does not include the start and turn phases, which might also influence swimmers E 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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TABLES AND FIGURES CAPTIONS

Table 1. Mean ± SD, effect sizes, and power values of the comparison between the three different conditions (n = 17).

	26º swimsuit	**18ºC swimsuit**	**18ºC wetsuit**	**Time effect**			
Variable	**Mean ± SD**	**Mean ± SD**	**Mean ± SD**	***F***	***P***	**Eta^2**	**Power**
Time endured (s)	304.91 ± 78.38	330.83 ± 52.97	334.11 ± 52.13	1.58	0.22	0.09	0.31
v (m· s^{-1})	1.23 ± 0.21	1.23 ± 0.17	1.24 ± 0.21	0.44	0.55	0.03	0.10
$\dot{V}O_{2peak}$ (mL · kg^{-1}· min^{-1})	47.70 ± 11.80†	44.70 ± 8.40$^{\beta}$	39.10 ± 8.30$^{\dagger\beta}$	12.64	0.00	0.44	0.99
$\dot{V}E$ (l/min^{-1})	129.60 ± 31.10†	119.70 ± 32.70	101.00 ± 26.70†	9.08	0.00	0.36	0.96
$\Delta\dot{V}E$ (l/min^{-1})	125.80 ± 30.60†	114.90 ± 33.40$^{\beta}$	95.10 ± 27.40$^{\dagger\beta}$	10.72	0.00	0.40	0.98
$[La^-]_{basal}$ (mmol·l^{-1})	2.25 ± 0.78	2.22 ± 1.08	2.18 ± 1.14	0.04	0.97	0.00	0.05
$[La^-]_{peak}$ (mmol·l^{-1})	10.25 ± 3.45†	7.99 ± 4.38$^{\beta}$	5.21 ± 2.65$^{\dagger\beta}$	14.36	0.00	0.47	1.00
$\Delta[La^-]$ (mmol·l^{-1})	8.00 ± 3.53†	5.77 ± 4.39	3.03 ± 2.68†	12.57	0.00	0.44	0.99
RPE	7.12 ± 1.32*†	5.35 ± 1.73*	6.00 ± 2.09†	9.38	0.00	0.37	0.97
HR_{max} (beats·min^{-1})	181.88 ± 19.24†	182.88 ± 18.79$^{\beta}$	154.18 ± 12.08$^{\dagger\beta}$	15.98	0.00	0.50	0.99
ΔHR (beats·min^{-1})	105.47 ± 18.39†	109.76 ± 21.71$^{\beta}$	74.12 ± 15.14$^{\dagger\beta}$	21.32	0.00	0.57	1.00
RF (breaths·min^{-1})	57.98 ± 19.27	51.61 ± 13.92	51.43 ± 15.76	2.12	0.14	0.12	0.40
ΔRF (breaths·min^{-1})	50.63 ± 19.90†	43.33 ± 14.36	41.43 ± 16.12†	3.70	0.04	0.19	0.64
RER	1.20 ± 0.20	1.30 ± 0.30	1.20 ± 0.30	0.69	0.51	0.04	0.16
ΔRER	0.50 ± 0.20	0.40 ± 0.30	0.40 ± 0.30	2.34	0.11	0.13	0.44
AnAL (kJ)	29.25 ± 4.08	29.25 ± 4.09	29.25 ± 4.09	1.72	0.20	0.10	0.24
AnL (kJ)	31.72 ± 14.73†	23.06 ± 18.78	12.18 ± 11.01†	12.99	0.00	0.45	0.99
Aer (kJ)	309.47 ± 97.08	314.02 ± 66.20	273.59 ± 57.60	2.43	0.10	0.13	0.45
AnAL (%)	8.69 ± 3.38	8.20 ± 1.48	9.60 ± 2.43	1.98	0.16	0.11	0.38
AnL (%)	8.60 ± 3.54†	6.15 ± 4.15	3.88 ± 3.34†	12.20	0.00	0.43	0.99
Aer (%)	82.72 ± 5.38	85.65 ± 4.36	86.52 ± 4.63	4.23	0.02	0.21	0.70
E (kJ)	370.44 ± 105.88*†	366.34 ± 74.16$^{*\beta}$	315.02 ± 60.71$^{\dagger\beta}$	4.20	0.02	0.21	0.70
C (kJ · m^{-1})	0.93 ± 0.26†	0.92 ± 0.19$^{\beta}$	0.79 ± 0.15$^{\dagger\beta}$	4.20	0.02	0.21	0.70
Ap (ml · kg^{-1}· min^{-1})	42.40 ± 12.30†	37.00 ± 5.90$^{\beta}$	32.20 ± 6.80$^{\dagger\beta}$	15.87	0.00	0.50	0.99
TDp (s)	18.98 ± 8.35	18.02 ± 6.90	16.44 ± 0.79	0.70	0.51	0.04	0.16
τp (s)	25.20 ± 12.17	26.21 ± 17.60	23.55 ± 15.46	0.18	0.83	0.01	0.08
SR (Hz)	0.56 ± 0.08†	0.55 ± 0.07$^{\beta}$	0.51 ± 0.07$^{\dagger\beta}$	19.99	0.00	0.56	1.00
SL (m)	2.25 ± 0.43†	2.28 ± 0.38$^{\beta}$	2.48 ± 0.48$^{\dagger\beta}$	16.81	0.00	0.51	1.00
SI (m^2·s^{-1})	2.83 ± 1.04†	2.86 ± 0.84$^{\beta}$	3.15 ± 1.17$^{\dagger\beta}$	8.45	0.00	0.35	0.95
ηp (%)	46.55 ± 8.96	45.90 ± 8.35	48.90 ± 10.93	3.16	0.06	0.16	0.56

Swimming speed (v), maximal oxygen consumption ($\dot{V}O_{2peak}$) ventilation ($\dot{V}E$), delta ventilation ($\Delta\dot{V}E$), 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 (HR_{max}), 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 τp), stroke rate, length and index (SR, SL and SI) and propelling efficiency (ηp). $^{*,\dagger \text{ and } \beta}$Differences between 26 vs 18ºC swimsuit, 26ºC swimsuit vs 18ºC wetsuit and 18ºC swimsuit vs wetsuit.

Table 2. Mean difference, coefficient intervals (CI), and effect sizes of the significant pairwise comparisons (n = 17).

Variable	Difference [95%CI]; %∆	p	Effect size (d)
26 swimsuit vs 18ºC swimsuit			
RPE	1.76 [0.81, 2.72]; -24.79%	0.000	1.16, Moderate
E (kJ)	4.11 [-59.93, 68.14]; -1.11%	0.050	0.04, Trivial
26 swimsuit vs 18ºC wetsuit			
$\dot{V}O_{2peak}$ ($mL \cdot kg^{-1} \cdot min^{-1}$)	8.62 [3.86, 13.39]; -18.07%	0.001	1.17, Moderate
VE (l/min)	28.57 [11.41, 45.73]; -22.05%	0.001	1.08, Moderate
∆VE (l/min)	30.71 [14.05, 47.36]; -24.41%	0.000	1.20, Large
$[La^-]_{peak}$ ($mmol \cdot l^{-1}$)	5.04 [3.09, 6.99]; -49.2%	0.000	1.68, Large
$\Delta[La^-]$ ($mmol \cdot l^{-1}$)	4.97 [2.93, 7.02]; -62.13%	0.000	1.58, Large
RPE	1.12 [0.02, 2.21]; -15.7%	0.045	0.66, Moderate
HR_{max} ($beats \cdot min^{-1}$)	27.70 [14.60, 40.81]; -15.23%	0.000	1.37, Large
∆HR ($beats \cdot min^{-1}$)	31.35 [16.95, 45.75]; -29.72%	0.000	1.41, Large
∆RF ($breaths \cdot min^{-1}$)	9.2 [-0.26, 18.65]; -18.17%	0.050	0.63, Moderate
AnL (kJ)	19.54 [11.56, 27.52]; -61.6%	0.000	1.59, Large
AnL (%)	4.72 [2.24, 7.19]; -54.87%	0.000	1.24, Large
E (kJ)	55.42 [-1.25, 112.09]; -14.96%	0.050	0.63, Moderate
C ($kJ \cdot m^{-1}$)	0.14 [0, 0.28]; -14.96%	0.050	0.63, Moderate
Ap ($ml \cdot kg^{-1} \cdot min^{-1}$)	10.1 [4.98, 15.23]; -23.86%	0.000	1.28, Large
SR (Hz)	0.05 [0.02, 0.08]; -8.68%	0.001	1.21, Large
SL (m)	-0.23 [-0.37, -0.1]; 10.39%	0.001	-1.11, Moderate
SI ($m^2 \cdot s^{-1}$)	-0.32 [-0.51, -0.14]; 11.33%	0.001	-1.11, Moderate
18 swimsuit vs 18ºC wetsuit			
$\dot{V}O_{2peak}$ ($mL \cdot kg^{-1} \cdot min^{-1}$)	5.62 [1.22, 10.03]; -12.57%	0.011	0.83, Moderate
∆VE (l/min)	19.8 [0.44, 39.17]; -17.24%	0.044	0.66, Moderate
$[La^-]_{peak}$ ($mmol \cdot l^{-1}$)	2.79 [0.15, 5.43]; -34.88%	0.037	0.69, Moderate
HR_{max} ($beats \cdot min^{-1}$)	28.70 [11.24, 46.18]; -15.69%	0.001	1.07, Moderate
∆HR ($beats \cdot min^{-1}$)	35.64 [18.24, 53.06]; -32.47%	0.000	1.33, Large
E (kJ)	51.31 [2.02, 100.6]; -14.01%	0.040	0.67, Moderate
C ($kJ \cdot m^{-1}$)	0.13 [0.01, 0.25]; -14.01%	0.040	0.68, Moderate
Ap ($ml \cdot kg^{-1} \cdot min^{-1}$)	4.76 [2.09, 7.43]; -12.86%	0.001	1.16, Moderate
SR (Hz)	0.04 [0.02, 0.05]; -6.83%	0.000	1.86, Large
SL (m)	-0.2 [-0.31, -0.09]; 8.59%	0.001	-1.15, Moderate
SI ($m^2 \cdot s^{-1}$)	-0.3 [-0.57, -0.02]; 10.34%	0.034	-0.70, Moderate

Borg rating of perceived exertion scale (RPE), total energy expenditure (E), Maximal oxygen consumption ($\dot{V}O_{2peak}$), ventilation ($\dot{V}E$), delta ventilation ($\Delta\dot{V}E$), peak blood lactate concentrations ([La-]peak), delta blood lactate concentrations (∆[La-]), maximal heart rate (HR_{max}), delta heart rate (∆HR), delta respiratory frequency (∆RF), anaerobic lactic contribution (AnL), energy cost (C), amplitude of the oxygen consumption (Ap), stroke rate, length, and index (SR, SL and SI).

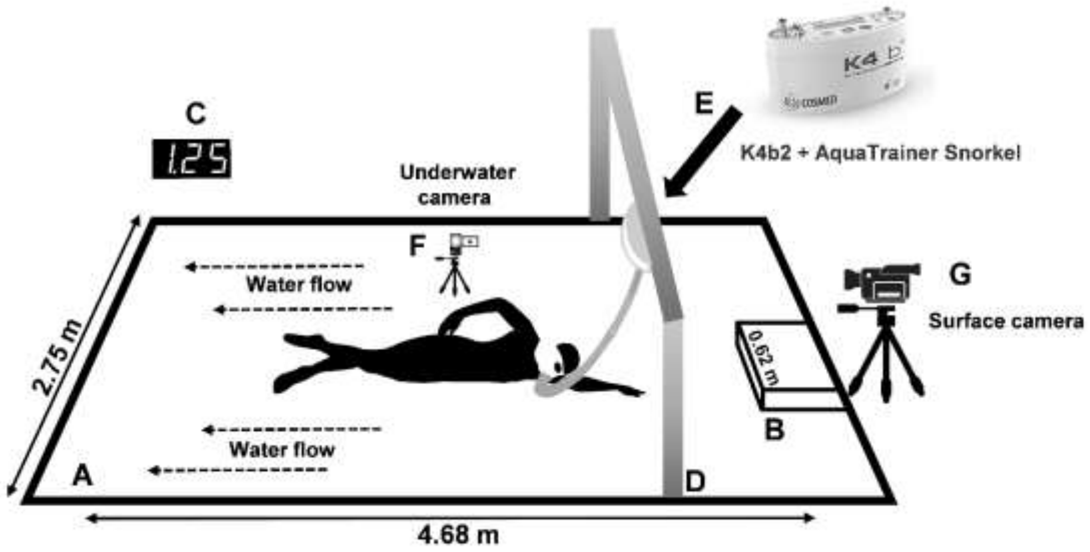

Figure 1. Graphic representation of the swimming flume. A: space for the swimmer; B: water channel; C: flume monitor where it was selected the swimming speed; D: mobile structure attached to the apparatus; E: K4b^2 and respiratory snorkel Aquatrainer; F: underwater sagittal camera; and G: surface front camera. Dashed arrows represent the water flow direction.

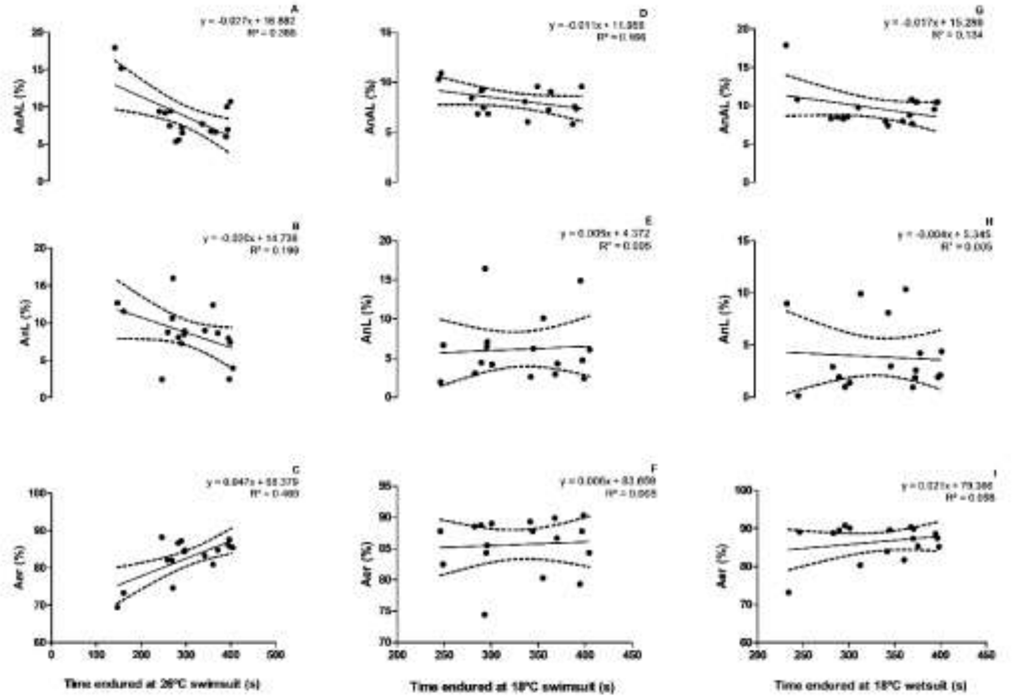

Figure 2. Relationships between the times endured on 400 m front crawl (at 26 and 18ºC with swimsuit and at 18ºC with wetsuit) with the energetic contribution percentages. Anaerobic alactic energy (AnAL; panels A, D, and G); Anaerobic lactic energy (AnL; panels B, E, and H) and; Aerobic energy (Aer; panels C, F, and I). Individual values (continuous lines) and 95% confidence intervals (dashed lines) are represented (n = 17).