1   **Title:** Swimming with swimsuit and wetsuit at typical vs cold-water temperatures (26 vs

2   18ºC)

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32   **ABSTRACT**

33

34   The study aimed to compare three swimming conditions in a swimming flume with water

35   at 26ºC (using swimsuit) and 18ºC (randomly with swimsuit and wetsuit). Seventeen

36   swimmers (32.4±14.7 years old, 175.6±0.06cm height, and 70.4±9.8kg body mass)

37   performed the three bouts until exhaustion at 400m front crawl pace (24h intervals).

38   ANOVA repeated measures compared the experimental conditions. Swimming at 26ºC

39   with swimsuit evidenced a higher metabolic demand (total energy expenditure; (E)),

40   comparing to 18ºC swimsuit (p=0.05) and with 18ºC wetsuit (p=0.04). The 26ºC swimsuit

41   condition presented higher peak oxygen uptake ($\dot{V}O_{2peak}$), blood lactate concentrations

42   ([La-]$_{peak}$), rate of perceived exertion (RPE), maximal heart rate (HR$_{max}$), anaerobic lactic

43   energy (AnL), E, energy cost (C), $\dot{V}O_2$ amplitude (Ap), and stroke rate (SR), but lower

44   stroke length (SL) and stroke index (SI) than 18ºC wetsuit. The 18ºC swimsuit condition

45   (comparing to wetsuit) lead to higher $\dot{V}O_{2peak}$, [La-]$_{peak}$, HR$_{max}$, E, C, Ap, and SR but

46   lower SL and SI. Swimming at aerobic power intensity with swim and wetsuit at 18ºC

47 does not induce physiologic and biomechanical disadvantages comparing to 26ºC, The

48 results suggested that the use of wetsuit might increase performance at 18ºC water

49 temperature for competitive master swimmers. Thus, its use is recommended in open

50 water swimming competitions when the water temperature is 18-20ºC.

51

52 **Key words:** Wet suit, Energetics, Biomechanics, Swimming Flume, Open water,

53 Neoprene.

54

55 **INTRODUCTION**

56

57 The use of wetsuit in open water swimming events is very frequent due to the

58 enhancement in speed compared to the use of swimsuit. The properties of a wetsuit

59 provoke an increase in buoyancy, leading to a reduction on hydrodynamic drag. It also

60 induce the increase in propelling efficiency (ηp) resulting in the decrease of the energy

61 cost of swimming (C) [1,2,3]. In fact, both former and contemporary studies showed a 5

62 to 7% of performance improvement on 400 m to 30 min swimming events when wearing

63 a wetsuit [1,4-6], probably due to body drag reduction caused by the buoyancy increment

64 [1]. However, there is a high variety of wetsuits models (full body, sleeveless long, and

65 short), some of which are more economic to swim with (presenting lower C values) than

66 others, related to the body cover [4,7,8].

67 The use of wetsuits in open water competitions is mandatory, allowed and forbidden

68 depending on water temperature (lower than 18, from 18 to 20, and higher of 20ºC,

69 respectively) [9]. The reason is to avoid hypothermia in cold-water temperatures [10].

70 When the immersion in with cold-water lead to the "cold-shock" physiological

71 phenomenon that is characterized by 1-3 min of hyperventilation and tachycardia

3

72 followed by an inspiratory gasp and by a heart rate (HR) decrease due to a blood flow

73 volume reduction [11]. However, these responses are only observed when swimming at

74 temperatures $\leq 15°C$ and in deep immersions [12,13] but it is not clarified if there are

75 physiologic and biomechanical modifications when swimming with a wetsuit at 18°C.

76 Open water swimming is different compared to pool swimming since there are no turns

77 and wall push-off glide, as the water volume is higher and water temperatures varies,

78 leading to particular cardiovascular and technical responses [14,15]. Therefore,

79 swimming in a flume at different water temperatures could be a good strategy to simulate

80 the typical continuous open water swimming both during training and testing. It was

81 recently observed that performing in a swimming flume and in a 25 m pool is

82 physiological and biomechanically different (independently of the suit used) [6]. In

83 addition, differences in fluid flow characteristics and the changes in their swimming

84 technique during continuous swimming might appear when fatigue occurs [16,17].

85 Knowing that the 400 m front crawl pace is well related with the velocity that elicits

86 maximal oxygen consumption ($\dot{V}O_{2max}$) and is a valid indicator of aerobic power (one of

87 the most important swimming training zones) in which the anaerobic contribution range

88 between 17 and 40% of the total energy expenditure [18,19], the aim of this study was to

89 compare swimming performed at two water temperatures (18 and 26°C) with and without

90 wetsuits. It was hypothesized that: (i) swimming with a swimsuit at 26 vs 18°C implies

91 lower physiological demands and higher ηp; and (ii) swimming at 18°C with swimsuit is

92 less efficient and economic than performing with a wetsuit.. Water temperatures of 26 and

93 18°C were selected since they represent the usual value at indoor swimming pools and

94 the limit under which the use of wetsuit is mandatory in open water swimming

95 competitions [9].

96

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

122   center of the swimming flume and to continue swimming until they were not able to keep

123   the pace. Swimmers had previous experience in flume swimming, using a breathing

124   snorkel and a nose clip, and abstained to take stimulant drinks and practice exhaustive

125   exercise 48 h prior to the trials. The trials were conducted at the same time of day (at a

126   room with 24 ± 1.5ºC air temperature and $51 \pm 2.7\%$ relative air humidity) and prior 24

127   h nutrition was controlled.

128

129   *Methodology*

130   Experimental trials were conducted in a 2.4 x 4.7 m Endless Pool (Elite Techno Jet Swim

131   7.5 HP, Aston PA, USA), with its flow speed measured at 0.30 cm depth using an FP101

132   flow probe device (Global Water, Gold River, CA) [21]. A $K4b^2$ (Cosmed, Rome, Italy)

133   breath-by-breath portable gas analyzer which allows the direct measurement of

134   respiratory and pulmonary gas exchange variables, being suspended at 1.8 m above the

135   water surface (Figure 1). The gas analyzer was attached to a low hydrodynamic resistance

136   respiratory snorkel and valve system (Aquatrainer, Cosmed, Rome, Italy) [14,22] and was

137   calibrated with 16% O_2 and 5% CO_2 concentration gases before each testing session. HR

138   was measured using telemetry (Polar Wearlink, Kempele, Finlandia) synchronized with

139   the portable gas analyzer. A surface and underwater cameras (Nikon Corporation, Japan

140   and Panasonic Full-HD HX-A500, Osaka, Japan), operating at 50 Hz and placed on the

141   swimming flume frontal and sagittal plans (respectively), were used to assess the

142   biomechanical variables (see below). A pre-calibrated space was used as a reference for

143   video analysis with one meter wide and 14 points used for calibrations, situated in the

144   center of the swimming flume [6].

145

146   Insert Figure 1

147

Data Analysis

149 $\dot{V}O_2$ data was analyzed using the VO2FITTING open and free software [23], with a

150 mono-exponential model adjusting the best profile for the three experimental conditions

151 (equation 1):

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

152 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-

153 exercise last 2 min average), H represents the Heaviside step function and Ap, TDp and

154 τ_p are the fast $\dot{V}O_2$ component amplitude, time delay and time constant (respectively)

155 [23]. $\dot{V}O_2$ values included only those between $\dot{V}O_2 \pm 4$ SD, decreasing the noise between

156 breaths caused when swimmers swallow water, cough or the signal is interrupted [24].

157 Then, individual breath-by-breath $\dot{V}O_2$ responses were smoothed using a three-breath

158 moving average and time averaged every 10 s [23,24] allowing the highest incidence of

159 $\dot{V}O_2$ plateau occurrence regardless the distance performed [24]. Peak oxygen

160 consumption ($\dot{V}O_{2peak}$) and other physiological variables, as maximal heart rate (HR_{max})

161 and respiratory exchange ratio (RER), were obtained from the last 30 s of each trial.

162 The total energy expenditure (E) was estimated as the sum of aerobic (Aer), anaerobic

163 lactic (AnL) and anaerobic alactic (AnAL) energy contributions, with the first two

164 calculated, respectively, from the time integral of the net $\dot{V}O_2$ vs time relationship and

165 using the following equation [25,26]:

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

166 where $[La^-]_{net}$ is the difference between the blood lactate concentration ($[La^-]$) before and

167 after exercise ($[La-]_{peak}$), β is the constant for O_2 equivalent of $[La^-]_{net}$ (2.7 ml $\cdot$ kg $\cdot$ min$^-$

168 ^{1}) and M is the swimmer body mass in kilograms. Afterwards, these energy contributions

169 were expressed in kJ assuming an energy equivalent of 20.9 kJ $\cdot$ L^{-1} [19]. The AnAL was

170   estimated from the maximal phosphocreatine splitting in the contracting muscle, using

171   this equation [25]:

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

172   where PCr is the rest phosphocreatine concentration, t is the exercise time, τ is the PCr

173   splitting time constant at exercise onset (23.4 s) and M is the body mass. Then, AnAL

174   was expressed in kJ by assuming an energy equivalent of 0.468 kJ $\cdot$ mM and a

175   phosphate/oxygen ratio of 6.25 [27]. C was obtained as the ratio between E and distance

176   swam at 400 m front crawl pace [28]. Capillary blood samples (25 μL) were collected

177   from the fingertip immediately after each trial (and at the 1, 3, 5 and 7 min of the recovery

178   period) using a portable lactate analyzer (Lactate Pro analyzer, Arkray, Inc., Kyoto,

179   Japan) to assess $[La\text{-}]_{peak}$ [6,29]. In addition, immediately after each trial, swimmers rated

180   their perceived exertion (RPE) on a Borg scale [24].

181   Stroke rate (SR) was obtained measuring three consecutive upper limbs cycles, stroke

182   length (SL) was calculated from the ratio between v and corresponding SR [14] and stroke

183   index (SI), a measure of swimming efficiency, was calculated by multiplying v by SL

184   [19]. Finally, ηp was estimated as follow [30]:

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

185   where l is the distance between the shoulder and wrist during the insweep (with the hand

186   situated exactly under the shoulder) Reference points were drawn at the shoulders, hips

187   and wrists to allow a proper biomechanical analysis. The distance between the points

188   were calculated with 2D motion analysis software Kinovea (version 0.8.15). For both

189   upper limbs due to a mirror was use to digitalize the upper limb of the left side of the

190   swimming flume.

191

192   *Statistical Analysis*

193   IBM SPSS Statistics (version 20, IBM SPSS, Chicago, USA) was used to data analysis,

194   with Shapiro-Wilk confirming its normality and homogeneity. ANOVA repeated

195   measures was computed to compare the three experimental conditions. Sphericity was

196   verified by means of the Mauchly test and adjusted according to the Greenhouse-Geisser

197   procedure when the significance of the F-ratios were not met. Bonferroni post hoc was

198   performed to locate the pairwise differences between the means ($p < 0.05$) with 95% of

199   confidence interval (CI). The Cohen´s d effect was calculated (0 to 0.19 trivial, 0.2 to

200   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

201   perfect) [6]. The relationships between the time endured in the different trials and the

202   corresponding energetic contributions were assessed with Pearson´s correlations

203   coefficients (r) and linear regression analysis.

204

205   **RESULTS**

206

207   Comparisons between experimental conditions conducted at different temperatures and

208   swimming suits at the 400 m front crawl pace are presented in Table 1. Bonferroni post

209   hoc analysis showed that E was different between the three comparisons. Nevertheless,

210    $\dot{V}O_{2peak}$, HR_{max}, $[La\text{-}]_{peak}$, C, Ap, SR, SL, and SI were different in between 26 swimsuit

211   and 18ºC swimsuit and between 18 swimsuit and 18ºC wetsuit conditions (Table 2). In

212   Table 1 it could be observed the percentual contribution of each energy system for the

213   overall swimming performance at each water temperature and suit condition. However,

214   only the AnL contribution showed differences between 26 swimsuit and 18ºC wetsuit

215   conditions (Table 2). Complementarily, in the 26ºC swimsuit condition, the time endured

216   at the aerobic power pace was directly related with Aer ($r = 0.69$; $p < 0.001$; Figure 2,

217   panel C) and inversely related with AnAL ($r = -0.62$; $p < 0.001$; Figure 2, panel A). No

218   statistically relationships were observed between swimming performance and energetic

219   contributions in the two other studied conditions (18ºC swimsuit and 18ºC wetsuit) as it

220   is shown in Figure 2.

221

222   Insert Table 1

223   Insert Table 2

224   Insert Figure 2

225

226   **DISCUSSION**

227   The main aim of the current study was to assess relevant physiological and biomechanical

228   variables while swimming to exhaustion at each individual 400 m front crawl pace (i.e.,

229   at the aerobic power intensity) using swim and wetsuits at typical and cold-water

230   temperatures. Contrary to our expectation, swimming with a swimsuit at 18ºC did not

231   increase swimmers physiological demands (even enduring 20-25 s longer) compared to

232   performing at representative swimming pool water temperature (26ºC). Additionally, as

233   anticipated, swimming at 18ºC with swimsuit was less economic than with wetsuit (and

234   lower physiological variables values and better technical characteristics were observed in

235   this latter condition) accordingly with previous reports of better performances when

236   wearing wetsuits [1,4,6].

237   As referred before, using a wetsuit at open water competitions with 18ºC water

238   temperature is optional [9]. It is known that subjects submerged in cold-water suffer a

239   cold-shock response that might lead to vasoconstriction and blood flow reduction [11],

240   particularly when using regular swimsuits that do not give any relevant protection against

241   low water temperatures. However, only RPE and E showed differences between the 26

242   and 18ºC swimsuit conditions. The reason might be that this water temperature was not

243   sufficient to cause significant cold-shock responses and/or the exposure time was enough

244   to reduce the metabolic responses of cold water (which is studied to be subsided after the

245   first 5 min of immersion time [31]) and in the current study, the maximum time swam at

246   18ºC water temperature was ~6.40 min. Still, when using a wetsuit at 18ºC, an evident

247   decrease of the cardiorespiratory and technical variables was found, evidencing that this

248   condition required lower E and C values compared to 18º swimsuit as it can be observed

249   in Table 2 (p = 0.04; d = 0.67 and p = 0.04; d = 0.68, respectively) (i.e., it was more

250   economic than swimming with a swimsuit both at 26 and 18ºC).

251   Regarding oxygen kinetics at the primary cardiorespiratory response, it was observed that

252   τ_p was > 20 s (as reported before [32]), with no differences between the three experimental

253   conditions. TDp also was similar between conditions, with values ~10-20 s. However, the

254   higher Ap values for the conditions 26ºC swimsuit vs 18ºC wetsuit and 18ºC swimsuit vs

255   18ºC wetsuit might indicate that the Aer contribution was accentuated by cold water and

256   wetsuit use. In addition, the AnL contributions were higher at 26 compared to 18ºC

257   wetsuit, in accordance with the [La-]$_{peak}$ values, an indicator of anaerobic energy

258   requirement [27]. This, plus the use of wetsuit in the cooler condition, might justify why

259   swimmers were able to maintain the time endured in all experimental conditions. When

260   swimming at 18ºC without wetsuit, swimmers maintained the pace eventually due to the

261   cold-shock response that lead to higher HR$_{max}$ values [11].

262   In fact, when wearing a wetsuit, swimmers lower limbs sinking torque is less expressive,

263   decreasing their hydrodynamic drag and, consequently, the C for the same speed [33].

264   This was observed in the current study with a SL and SI increment (and a SR decrease)

265   at the 18ºC wetsuit condition even if usually the wetsuit thickness limits the shoulder

266   range of motion leading to a SR increase [34]. This is in line with previously reported

267   data when using a wetsuit comparing to swimsuit in a flume at the aerobic power intensity

268   [6]. As time to exhaustion at $\dot{V}O_{2max}$ is directly influenced by C, SL and SI [17,18,33],

269   the lower values in time endured at 26ºC swimsuit seems to express that swimmers

270   experienced it as the most difficult metabolic and technical condition. This can be

271   observed by the higher RPE, [La-]$_{peak}$, $\dot{V}O_{2max}$, and SR values (also with higher values

272   of power), although the learning effect might also influenced the results since the warmer

273   condition was performed first.

274   In accordance with these data, a swimming efficiency rise at the 18ºC wetsuit exertion

275   was expected. However, when comparing the ηp at the different conditions, the p value

276   although very close to 0.05 fell short of statistical meaning (with lower eta^2 and power).

277   This might be justified by methodological constraints, particularly by the fact that the ηp

278   calculation was limited to the SR, neither considering technical aspects responsible for

279   propulsion nor thrust-producing vortices. Complementarily, the lower values of l might

280   have induced higher efficiency values [30], for which the swimming ability is an

281   important factor. Eventually, if another ηp assessment method was used (e.g., by

282   assessing the ratio of the speed of the center of mass to three dimensional speed of the

283   right and left upper limbs during underwater phase [29]) the results might be different.

284   It is also important to highlight that, even if a swimming flume allows to better set and

285   control the swimmers pace, it has some specificities that might influence both

286   physiological and biomechanical variables. In fact, the hydrodynamic resistance that

287   swimmers need to overcome is different from free swimming due to its non-laminar water

288   flow, consequently influencing swimmers technique and E [6,16]. The higher the water

289   temperature, the lower the water density and, consequently, the lower the hydrodynamic

290   resistance [35]. However, at higher temperatures the body temperature increases, and

291   more energy requirement might be necessary for self-regulation, probably explaining the

292   higher energetics requirement values at the 26ºC condition.

293   Furthermore, flume swimming does not include the start and turn phases, which might

294   also influence swimmers E comparing to swimming in a pool. However, these swimmers

295   participate in open water and triathlon competitions hence, swimming in a flume might

296   replicate real swimming events. In addition, though our swimmers had considerable

297   experience using the swimming flume and the breathing snorkel, we could accept that

298   their technique might be affected and, in consequence, their energy requirements could

299   be different from swimming unimpeded in a pool, but as the aim of the study is related to

300   open water, the used of a swimming flume could be a more ecologically valid method to

301   measure continuous swimming than swimming pool. In conclusion, when using a wetsuit

302   at 18ºC, an evident decrease of the cardiorespiratory and technical variables was found,

303   demonstrating that this condition require lower E and C values. Thus, it was more

304   economic than swimming with a swimsuit both at 26 and 18ºC. The results suggested that

305   the use of wetsuit might increase performance at 18ºC water temperature for competitive

306   master swimmers.

307

308   **PRACTICAL APPLICATIONS**

309

310   In the current study it was underscored the importance of the use of wetsuit at 18ºC for

311   open water swimming competitions since it allows a better technique and effort economy

312   (comparing to wearing a swimsuit), meaning that for the same energy input its use will

313   allow better performances. Also, since the anaerobic threshold pace happens at ~90% of

314   the 400 m intensity [18,19], the physiologic and biomechanical variables values displayed

315   in our study could be useful for evaluating the open water swimmers and triathletes

316   performance that typically happens below or at that boundary [14,15]. Notwithstanding

317   the swimming flume particularities (that should be considered when analysing data), its

13

318 use makes the process of evaluating swimmers easier both at the physiologic and

319 biomechanical areas, reason why swimmers in general (and open water specialists in

320 particular) should use it on a regular basis to follow-up their training process.

321

322 **CONFLICT OF INTEREST**

323

324 Authors have no conflict of interest to report.

325

326 **REFERENCES**

327

328 1. Chatard JC, Senegas X, Selles M et al. Wet suit effect - A comparison
329 between competitive swimmers and triathletes. Med Sci Sports Exerc
330 1995; 27: 580-586
331 2. Toussaint HM, Bruinink L, Coster R et al. Effect of a triathlon wet suit
332 on drag during swimming. Med Sci Sports Exerc 1989; 21: 325-328
333 3. Zamparo P, Cortesi M, Gatta G. The energy cost of swimming and its
334 determinants. Eur J Appl Physiol 2019; 120: 41-66
335 4. Cordain L, Kopriva R. Wetsuits, body density and swimming
336 performance. Br J Sports Med 1991; 25: 31-33
337 5. De Lucas RD, Balikian P, Neiva CM et al. The effects of wet suits on
338 physiological and biomechanical indices during swimming. J Sci Med
339 Sport 2000; 3: 1-8
340 6. Gay A, López-Contreras G, Fernandes RJ, Arellano R. Is Swimmers'
341 Performance Influenced by Wetsuit Use? Int J Sports Physiol Perform
342 2020; 15: 46-51
343 7. Perrier D, Monteil K. Wetsuits and performance: Influence of technical
344 abilities. J Hum Movement Stud 2001; 41: 191-207
345 8. Trappe TA, Pease DL, Trappe SW et al. Physiological responses to
346 swimming while wearing a wet suit. Int J Sports Med 1996; 17: 111-
347 114
348 9. Fédération Internationale de Natation / Marculescu C. Swimwear for
349 open water swimming events. FINA Rules Memorandum. 2017.
350 https://www.fina.org/swimming/approved-swimwear
351 10. Parsons L, Day S. Do wet suits affect swimming speed? Br J Sports
352 Med 1986; 20: 129-131
353 11. Stocks JM, Taylor NA, Tipton MJ, Greenleaf JE. Human physiological
354 responses to cold exposure. Aviat Space Environ Med 2004; 75: 444-457

355 12. Bleakley CM, Davison GW. What is the biochemical and physiological
356 rationale for using cold-water immersion in sports recovery? A
357 systematic review. Br J Sports Med 2010; 44: 179-187
358 13. Broatch JR, Petersen A, Bishop DJ. The Influence of Post-Exercise
359 Cold-Water Immersion on Adaptive Responses to Exercise: A Review
360 of the Literature. Sports Med 2018; 48: 1369-1387
361 14. Zacca R, Neves V, da Silva Oliveira T et al. 5 km front crawl in pool
362 and open water swimming: breath-by-breath energy expenditure and
363 kinematic analysis. Eur J Appl Physiol 2020; 120: 2005-2018
364 15. Zamparo P, Bonifazi M, Faina M et al. Energy cost of swimming of elite
365 long-distance swimmers. Eur J Appl Physiol 2005; 94: 697-704
366 16. Espinosa HG, Nordsborg N, Thiel DV. Front crawl swimming analysis
367 using accelerometers: A preliminary comparison between pool and
368 flume. Procedia Eng 2015; 112: 497-501
369 17. Pelarigo JG, Greco CC, Denadai BS et al. Do 5% changes around
370 maximal lactate steady state lead to swimming biophysical
371 modifications? Hum Mov Sci 2016; 49: 258-266
372 18. Fernandes RJ, Vilas-Boas JP. Time to Exhaustion at the VO2max
373 Velocity in Swimming: A Review. J Hum Kinet 2012; 32: 121-134
374 19. Zacca R, Azevedo R, Silveira RP et al. Comparison of incremental
375 intermittent and time trial testing in age-group swimmers. J Strength
376 Cond Res 2019; 33: 801-810
377 20. Harriss D, MacSween A, Atkinson G. Ethical standards in sport and
378 exercise science research: 2020 update. Int J Sports Med 2019; 40: 813-
379 817
380 21. McLean SP, Palmer D, Ice G et al. Oxygen uptake response to stroke
381 rate manipulation in freestyle swimming. Med Sci Sports Exerc 2010;
382 42: 1909-1913
383 22. Ribeiro J, Figueiredo P, Guidetti L et al. AquaTrainer® snorkel does
384 not increase hydrodynamic drag but influences turning time. Int J
385 Sports Med 2016; 37: 324-328
386 23. Zacca R, Azevedo R, Figueiredo P et al. VO2FITTING: A Free and
387 Open-Source Software for Modelling Oxygen Uptake Kinetics in
388 Swimming and other Exercise Modalities. Sports 2019; 7: 31
389 24. de Jesus K, Guidetti L, de Jesus K et al. Which Are The Best VO2
390 Sampling Intervals to Characterize Low to Severe Swimming
391 Intensities? Int J Sports Med 2014; 35: 1030-1036
392 25. Sousa A, Figueiredo P, Pendergast D et al. Critical Evaluation of
393 Oxygen-Uptake Assessment in Swimming. Int J Sports Physiol
394 Perform 2014; 9: 190-202
395 26. Di Prampero P, Pendergast D, Wilson D, Rennie D. Blood lactic acid
396 concentrations in high velocity swimming. J Swimming medicine IV
397 1978; 249-261
398 27. Zamparo P, Capelli C, Pendergast D. Energetics of swimming: a
399 historical perspective. Eur J Appl Physiol 2011; 111: 367-378
400 28. Fernandes RJ, Marinho DA, Barbosa TM, Vilas-Boas JP. Is time limit
401 at the minimum swimming velocity of VO2 max influenced by stroking
402 parameters? Percept Mot Skills 2006; 103: 67-75

403 29. Figueiredo P, Toussaint HM, Vilas-Boas JP, Fernandes RJ. Relation
404   between efficiency and energy cost with coordination in aquatic
405   locomotion. Eur J Appl Physiol 2013; 113: 651-659
406 30. Zamparo P, Pendergast D, Mollendorf J et al. A. An energy balance of
407   front crawl. Eur J Appl Physiol 2005; 94: 134-144
408 31. Johnson DG, Hayward J, Jacobs T et al. Plasma norepinephrine
409   responses of man in cold water. J Appl Physiol 1977; 43: 216-220
410 32. Reis JF, Alves FB, Bruno PM et al. Oxygen uptake kinetics and middle
411   distance swimming performance. J Sci Med Sport 2012; 15: 58-63
412 33. Zamparo P, Cortesi M, Gatta G. The energy cost of swimming and its
413   determinants. Eur J Appl Physiol 2020; 120: 41-66
414 34. Tomikawa M, Shimoyama Y, Nomura T. Factors related to the
415   advantageous effects of wearing a wetsuit during swimming at
416   different submaximal velocity in triathletes. J Sci Med Sport 2008; 11:
417   417-423
418 35. Arellano R. Entrenamiento técnico de natación. Real Federación
419   Española de Natación, Escuela Nacional de Entrenadores, 2010

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TABLES AND FIGURES CAPTIONS

439 **Table 1.** Mean ± SD, effect sizes, and power values of the comparison between the three

440 different conditions (n = 17).

Variable	26º swimsuit Mean ± SD	18ºC swimsuit Mean ± SD	18ºC wetsuit Mean ± SD	Time effect F	P	Eta²	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
Δ**RER**	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 (m²·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). *,† and $^\beta$Differences between 26 vs 18ºC swimsuit, 26ºC swimsuit vs 18ºC wetsuit and 18ºC swimsuit vs wetsuit.

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Table 2. Mean difference, coefficient intervals (CI), and effect sizes of the significant

| Variable	Difference [95%CI]; %Δ	p	Effect size (d)
26 swimsuit vs 18⁰C 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 18⁰C wetsuit			
$\dot{V}O_{2peak}$ (mL · kg⁻¹· 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
ΔVE (l/min)	30.71 [14.05, 47.36]; -24.41%	0.000	1.20, Large
[La⁻]peak (mmol·l⁻¹)	5.04 [3.09, 6.99]; -49.2%	0.000	1.68, Large
Δ[La⁻] (mmol·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
HRmax (beats·min⁻¹)	27.70 [14.60, 40.81]; -15.23%	0.000	1.37, Large
ΔHR (beats·min⁻¹)	31.35 [16.95, 45.75]; -29.72%	0.000	1.41, Large
ΔRF (breaths·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 · m⁻¹)	0.14 [0, 0.28]; -14.96%	0.050	0.63, Moderate
Ap (ml · kg⁻¹· 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 (m²·s⁻¹)	-0.32 [-0.51, -0.14]; 11.33%	0.001	-1.11, Moderate
18 swimsuit vs 18⁰C wetsuit			
$\dot{V}O_{2peak}$ (mL · kg⁻¹· min⁻¹)	5.62 [1.22, 10.03]; -12.57%	0.011	0.83, Moderate
ΔVE (l/min)	19.8 [0.44, 39.17]; -17.24%	0.044	0.66, Moderate
[La⁻]peak (mmol·l⁻¹)	2.79 [0.15, 5.43]; -34.88%	0.037	0.69, Moderate
HRmax (beats·min⁻¹)	28.70 [11.24, 46.18]; -15.69%	0.001	1.07, Moderate
ΔHR (beats·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 · m⁻¹)	0.13 [0.01, 0.25]; -14.01%	0.040	0.68, Moderate
Ap (ml · kg⁻¹· 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 (m²·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 (V̇E), delta ventilation (ΔV̇E), peak blood lactate concentrations ([La-]peak), delta blood lactate concentrations (Δ[La-]), maximal heart rate (HRmax), delta heart rate (ΔHR), delta respiratory frequency (ΔRF), anaerobic lactic contribution (AnL), energy cost (C), amplitude of the oxygen consumption (Ap), stroke rate, length, and index (SR, SL and SI).

444 pairwise comparisons (n = 17).

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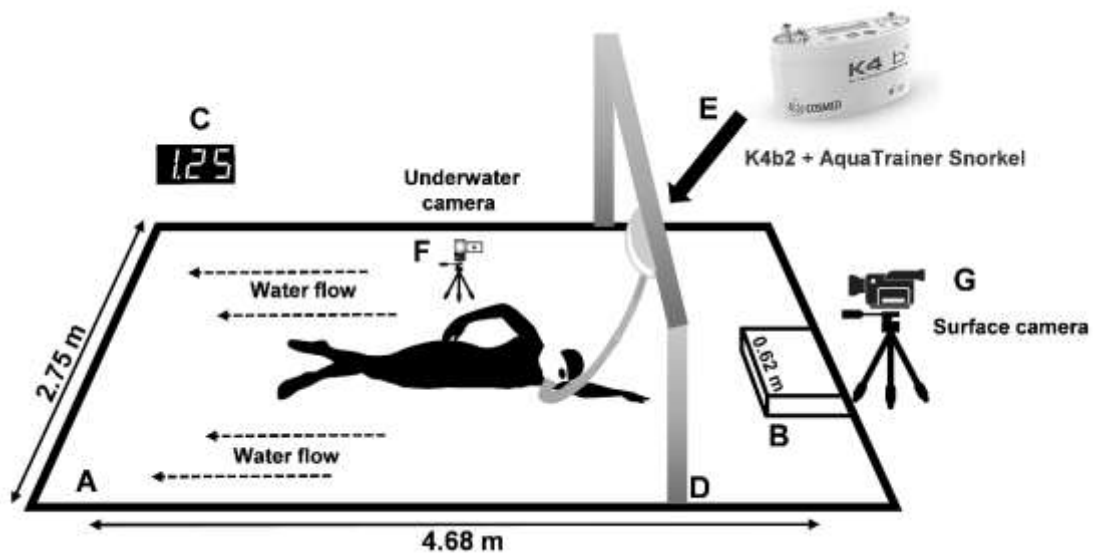
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451 **Figure 1.** Graphic representation of the swimming flume. A: space for the swimmer; B:

452 water channel; C: flume monitor where it was selected the swimming speed; D: mobile

453 structure attached to the apparatus; E: K4b[2] and respiratory snorkel Aquatrainer; F:

454 underwater sagittal camera; and G: surface front camera. Dashed arrows represent the
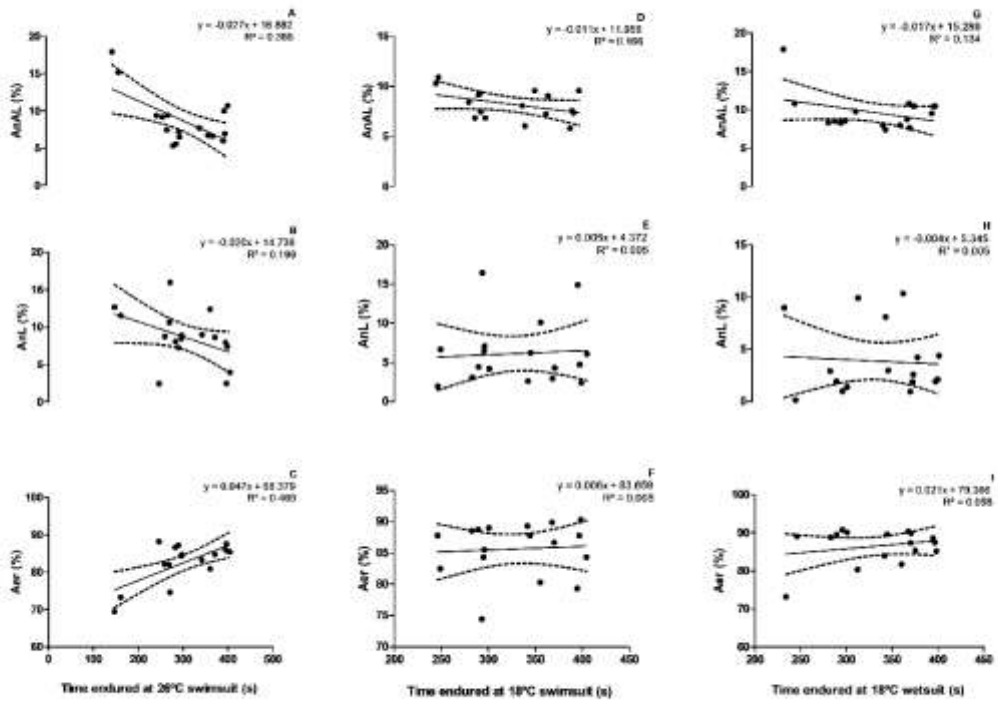
455 water flow direction.

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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).

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