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The Effects of a Wetsuit on Biomechanical, Physiological, and Perceptual Variables in Experienced Triathletes

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The effects of wetsuit on biomechanical, physiological and perceptual variables in experienced triathletes

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Keywords:	open water, swimming kinematics, drag, fatigability, comfort

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1 ABSTRACT

2 **Purpose:** Wetsuit use has been shown to change swim biomechanics and thus increase performance,
3 but not all athletes are comfortable with its use because of possible modifications in motor
4 coordination. The aim of this study was to evaluate the effects of wetsuit on biomechanical,
5 physiological and perceptual variables. **Methods:** Eleven national and international level triathletes,
6 familiar with wetsuit use, performed 7x200 m in front-crawl at constant pre-set speed twice, with and
7 without a full-wetsuit. The trunk incline (TI) and index of coordination (IdC) were measured stroke-
8 by-stroke using video-analysis. Stroke, breathing and kick count and timing (as breathing/kick action
9 per arm stroke cycle), stroke (SL) and underwater length were analysed using inertial measurement
10 unit (IMU) sensors. Heart rate (HR), rate of perceived exertion (RPE), swimming comfort were
11 monitored during the task. **Results:** A lower TI, IdC, number of strokes, kicks and breathing, HR and
12 RPE for each 200m was found in wetsuit compared to swimsuit condition. Higher values of SL and
13 underwater length were found in wetsuit, while no differences were found in swimming comfort and
14 timing of kicks and breathings. An increase for swimsuit condition in number of strokes and
15 breathings, HR and RPE were found during the task compared to the first 200m. **Conclusion:** Wetsuit
16 use reduces TI, thus drag, increases propelling proficiency and shows lower fatigability, without
17 modifying motor coordination, compared to a swimsuit use at the same speed. The use of a wetsuit
18 during training sessions is recommended, to increase the comfort and the positive effects on
19 performance.

20
21 **Keywords:** open water, swimming kinematics, drag, fatigability, comfort

22

23 INTRODUCTION

24

25 Swimming in open water leads athletes to face environmental challenges not typically present in pool
26 environment such as swimming in packs, unpredictable waves and currents, salt water, absence of
27 turns and cold water temperature exposure^{1,2}. To prevent hypothermia, the use of a wetsuit is
28 permitted in official competitions when water temperature is below 20°C in open water³ and
29 triathlon up to 1500 m, below 22°C in longer distances and below 24.6°C in age-group
30 competitions⁴. A wetsuit is made of neoprene, a synthetic rubber that contains small bubbles of gas,
31 that have the primary role of reducing convective heat loss⁵. The thickness of a wetsuit usually differs
32 between the different parts of the athlete's body, but it cannot exceed 5 mm in triathlon⁴ and it cannot
33 be thinner than 3 mm in open water swimming competitions³. Other than protecting from cold water
34 exposure, wetsuit use has shown effects on buoyancy, friction drag⁶⁻⁸ and propelling proficiency
35 (expressed as stroke length (SL) and stroke index (SI))^{7,9-14}, leading to a performance enhancement⁶⁻
36 ²². On the other hand, athletes have reported a lower comfort in the upper arms^{12,17} at the end of a
37 swimming task and an inhibition in kicking action^{11,17,20} while swimming with a wetsuit²². The
38 amplitude of these effects seems to be affected by how familiar the athlete is with a wetsuit, by his/her
39 swimming ability^{7,12} and by the model of wetsuit used^{12,17,18,22}. Although wetsuit use has been
40 reported to improve performance⁶⁻²², its effects on motor coordination and comfort during a task
41 simulating competition effort are lacking²².

42 The majority of the studies investigating the effects of swimming with a wetsuit tested athletes only
43 in short distance^{7-9,12,16,17,19} or short time^{13,15,18} tasks²². However, both open water swimmers and
44 triathletes swim in open water from several minutes to hours (up to 25²³ and 3.8 km⁴ in official
45 competitions, respectively). In such long efforts the sensation of fatigue plays a fundamental role and
46 a change in biomechanical, physiological and perceptual variables, defined as fatigability²⁴, could
47 affect performance. During swimming locomotion the maintenance of a correct motor coordination
48 has a critical role in the optimization of the ratio between propulsion and energy expenditure^{25,26}. In

49 this context, given the already reported effects on biomechanical⁶⁻¹⁷, physiological^{8,9,13,16,19,27} and
50 perceptual^{12,13,17,18,27} variables, a prolonged wetsuit use could have an additional role on fatigability
51 and overall performance. Very few studies tested athletes while swimming with a wetsuit for longer
52 time tasks²² (20-75 minutes^{10,27-29}) reporting a mitigation in the decrease of core/skin temperature in
53 cold water^{10,29} and a decrease²⁷ or no difference¹⁰ in heart rate (HR). Moreover, only one study
54 evaluated the effects of fatigability on upper limbs action comparing the first and the last length
55 during a pre-set distance of 1500 m¹⁴. However, comparing wetsuit with swimsuit during a pre-set
56 distance task could lead to artefactual results. Indeed, all the results found could be attributable to the
57 higher swimming speed reported with a wetsuit^{7-9,12,14,16,17,22} instead of as a direct effect of the wetsuit
58 per se²².

59 The aim of this study was to evaluate the effects of a full body wetsuit on biomechanical,
60 physiological and perceptual variables during a 7x200 m front-crawl at constant speed (equal to
61 Olympic distance race pace) training session in experienced triathletes. We hypothesized an effect of
62 wetsuit use on biomechanical variables that would mitigate fatigability in front-crawl at pre-set speed,
63 compared to swimsuit. Moreover, because of the tight-fitting, we hypothesized that wetsuit use could
64 decrease the comfort and motor coordination of triathletes.

65

66 **METHODS**

67 *Participants*

68 Fifteen (five females) national and international level triathletes (Tier 3-4³⁰) were recruited for the
69 study. All triathletes were familiarized with the wetsuit use and with the rate of perceived exertion
70 scale (CR-10 modified, Italian version³¹). The CR10 is routinely used during triathlon training
71 camps³² and commonly utilized to monitor training load, other than widely promoted by the
72 Federation during training courses for coaches. Four triathletes (one female) were excluded (see
73 methodology section), therefore only 11 triathletes were analysed. Detailed information about
74 triathletes is provided in Table 1. Information regarding procedures was provided to each participant,
75 written informed consent and personal information treatment were obtained. The study was approved
76 by the Institutional Review Board (CAR 38/2020) and in accordance with the principles of the
77 Declaration of Helsinki.

78

79 *Table 1*

80

81 *Design*

82 Each triathlete performed twice the same swimming protocol, once with the wetsuit and once with
83 the swimsuit, in a random and counterbalanced order (seven triathletes performed the wetsuit
84 condition first and eight the swimsuit) using a computer generated randomization order
85 (<https://www.graphpad.com/quickcalcs/randomize1/>). The sessions were performed just before the
86 competitive season, when athletes mostly utilize wetsuits, at the same time of the day with at least 48
87 h and no more than 7 days apart. The participants were instructed to maintain similar eating, sleeping
88 and training habits and avoid intensive exercise 48 h prior to the tests.

89

90 *Methodology*

91 Before the first test session, subjects filled in an online survey (Google Form, Google, USA) to collect
92 individual information such as age, height, training information and wetsuit use habits (see Table 1).
93 The tests were performed in an indoor pool (length: 33.33 m, water temperature= 28.4±0.5°C, air
94 temperature= 27.6±0.8°C) traditionally used by the triathletes. Prior to each test session body mass
95 and fat were estimated by an impedance balance (Mi Body composition Scale 2, Xiaomi, China).
96 A standard warm-up, self-paced swimming up to 15 minutes^{9,33}, was performed before each
97 swimming test. The swimming test consisted of a 7x200 m front-crawl constant speed protocol, with
98 1-minute rest between repetitions, performed at the individual average race speed of the Olympic

99 distance triathlon (1500 m, see Table 1). A sound pacer (Tempo Trainer, Finis, Italy) was placed
100 inside the swimming cap and the swimmer followed the audio-signal to synchronise with his pre-set
101 speed. The test in the wetsuit condition was performed using the full model wetsuit (covering the
102 whole body except for the face, hands and feet) of each triathlete (details in Table 1). The subjects
103 with a time difference between suit conditions in at least one repetition $>3\%$ (~ 1.9 s) were discarded
104 and not analysed because of possible differences in biomechanical variables as previously reported³⁴.
105 The test was recorded by an underwater camera (Hero4 Black, GoPro, USA, 120Hz) placed in the
106 sagittal plane of the swimmer. At least one to three complete stroke cycles were recorded each time
107 the participant passed in front of the camera. Black pen (swimsuit) or red tape (wetsuit) markers were
108 applied on the following anatomical landmarks in both sides of the body: acromion process, interior
109 angle of the scapula, great trochanter, fibula head and lateral malleolus. Kinovea software version
110 0.8.15 (Joan Charmant & Contrib.) was used to manually analyse frame-by-frame the video
111 sequences. Trunk incline (TI) was quantified using a video-based system³⁵. The arm stroke phases
112 events (entry, pull, push and recovery) were identified using video analysis to estimate the stroke
113 phase percentages and the index of coordination (IdC)³⁶. These variables were presented as mean
114 value of the first and the seventh repetition of each test.

115 Three IMU sensors (WaveTrack Inertial System waterproof, Cometa, Milan, Italy, 128 Hz,
116 accelerometer full scale: 16g, gyroscope full scale: $\pm 2000^\circ/\text{s}$) were placed on the occipital bone, on
117 the right wrist and 1 cm above the right lateral malleolus (Figure 1). The sensors were fixed with two
118 swimming caps on the head and with biadhesive/co-band tape on the limbs. The wrist IMU
119 automatically recognized the wrist entry instant in the water through the modulus of the signal output
120 of the gyroscope (angular velocity). Due to the shock effect of the water drag on wrist water touch,
121 an artefact in the smooth gyroscope signal was used for the wrist entry identification and detected
122 using the local maxima of the jerk. Furthermore, an algorithm computed the lateral face entry and
123 exit from the water surface recognizing with the peaks of the angular velocity of the occipital bone
124 sensors in the mediolateral head roll. Finally, the downbeat end of the foot during the flutter kick was
125 automatically detected applying the method described in Fulton et al. (2009)³⁷. The following
126 biomechanical variables were then calculated: breathing count (total, right and left side); percentage
127 count of left/right breathing; timing of breathing (left and right) with respect to stroke cycle duration,
128 starting with the right-hand entry; strokes count/lap; SL per lap; kicks count/lap; timing of kicks (first,
129 second and third, when effectuated) with respect to stroke cycle duration, starting with the right-hand
130 entry; underwater length from the push on the wall; index of synchronization (IdS)³⁸; SI; stroke-
131 breathing count ratio (ratio between stroke and breathing count). The start and the end of the
132 underwater phase were automatically recognized using the angular velocity of the ankle IMU for the
133 wall touch and of the wrist IMU for first-hand entry into the water, respectively. For more detailed
134 information about the set-up and analysis of IMU sensors data, we recommend referring to the article
135 published by Fantozzi et al. 2022³⁹.

136 The HR was continuously recorded by a bend sensor for swimming (HRM-Tri and Forerunner 935,
137 Garmin, USA) during the test and the mean value was estimated for each repetition. After each 200m,
138 the rate of perceived exertion (RPE) was collected (CR-10 modified scale, Italian version³¹). The
139 subjects also provided their swimming comfort during the rest phase by a scale ranging between -5
140 "Very bad", 0 "Neutral" and +5 "Very good" (based on feeling scale⁴⁰) answering the question "How
141 do you feel your swimming comfort?".

142
143 Figure 1

144 145 *Statistical Analysis*

146 The sample size of 15 was estimated a priori using G*Power 3.1, with a power of 0.7, alpha of 0.05
147 and d of 0.6 for t-test difference between two dependent means. The statistical package SPSS version
148 25.0 (IBM, Chicago, USA) for Windows OS was used for statistical analysis. Non-parametric
149 Friedman test, both with Kendall's W as effect size, was performed to assess differences between

150 conditions, to evaluate suit condition and between repetitions, to evaluate fatigability, in all variables.
151 Wilcoxon test, both with biserial correlation (r) as effect size, was run as post-hoc to assess pairwise
152 differences between the conditions for the same repetition and between each repetition with the first
153 one within the condition. The value of r was considered as: small (.100-.299), moderate (.300-.499),
154 large (.500-.699), very large (.700-.899) and extremely large ($\geq .900$)⁴¹.
155 The significance level was set at $p \leq 0.05$. Data are presented as median \pm interquartile range.

156

157 RESULTS

158

159 Triathletes completed the tests with a mean time difference of $1.09 \pm 0.47\%$ (~ 0.69 s) between suit
160 conditions, with an average time of 158.02 ± 11.12 s and 158.72 ± 11.95 s for wetsuit and swimsuit
161 condition, respectively. Four of the recruited triathletes achieved a time difference $>3\%$ ($5.0 \pm 2.0\%$,
162 corresponding to 7.73 ± 3.07 s) between conditions, with the higher times performed in the swimsuit
163 condition. These four subjects were discarded and not analysed as previously stated.

164

165 *Suit condition*

166 Lower TI ($p < .001$) (Figure 2) and a longer underwater phase (wetsuit 3.08 ± 0.46 m, swimsuit
167 2.71 ± 0.50 m; $p .004$) were found in wetsuit condition. Both number of strokes ($p < .001$) and kicks
168 ($p < .001$) were lower in wetsuit, with an associated higher SL ($p < .001$), SI ($p < .001$) compared to
169 swimsuit (Figure 3) and no difference in timing of kicking was found. Although a catch-up
170 coordination was observed in both conditions, lower values of IdC were found in wetsuit compared
171 to swimsuit ($p < .001$), both with a higher percentage in the no propulsive phases ($p < .001$): entry+catch
172 (A: wetsuit $32.35 \pm 8.87\%$, swimsuit $32.10 \pm 7.64\%$) and recovery (D: wetsuit $28.63 \pm 8.72\%$, swimsuit
173 $25.77 \pm 8.07\%$); and a lower percentage in the propulsive phases ($p < .001$): pull (B: wetsuit
174 $16.98 \pm 2.25\%$, swimsuit $19.22 \pm 3\%$) and push (C: wetsuit $23.35 \pm 1.57\%$, swimsuit $24.65 \pm 4.17\%$)
175 (Figure 3). No differences were found in IdS (wetsuit 0.06 ± 0.22 , swimsuit 0.01 ± 0.12 ; $p .911$). The
176 total (Figure 2) and right side number of breathings were lower in wetsuit (both $p < .001$), but not on
177 the left side ($p .726$). The higher stroke-breathing count ratio found (wetsuit 1.38 ± 0.43 , swimsuit
178 1.28 ± 0.32 ; $p < .001$) confirms the difference in number of breathings between conditions. However,
179 no difference was found in the total percentage of right (wetsuit $62.9 \pm 24.09\%$, swimsuit
180 $70.03 \pm 26.35\%$) and left side (wetsuit $37.85 \pm 23.63\%$, swimsuit $31.14 \pm 26.13\%$) breathings, nor in
181 the timing of breathings ($p .105$). Higher HR and RPE were recorded in swimsuit, (both $p < .001$) with
182 no differences in swimming comfort (wetsuit 0.1 ± 1.9 , swimsuit 0.7 ± 2.0 ; $p .206$) (Figure 2).

183

184 *Fatigability*

185 A fatigability effect was found for HR in both swimsuit and wetsuit (both $p < .001$) and for count of
186 strokes and breathings (both $p < .001$), SL ($p < .001$), stroke-breathing count ratio ($p < .001$) and RPE (p
187 $.001$) in swimsuit condition only (Figure 2 and 3).

188

189 Detailed data and statistical analysis results are provided in Supplementary Material (available
190 online).

191

192 Figure 2

193

194 Figure 3

195

196 DISCUSSION

197

198 Wetsuits are permitted in open water and triathlon events, depending on water temperature, age group
199 and distance to be covered, with the main purpose to prevent hypothermia²². Previous research has

200 shown an improvement in performance with wetsuit use by increasing buoyancy and gliding length
201 and by decreasing energy cost^{8,9,13,18,19}. However, athletes have reported a higher discomfort while
202 swimming with a wetsuit and some technical changes have been reported such as an inhibition in
203 kicking action^{17,20,21}. Our results have further strengthened what is already known by highlighting
204 that wetsuit use decreases trunk incline and drag leading to a delayed increase of effort. Contrary to
205 our hypothesis, motor coordination (i.e. stroke coordination model, upper and lower limb
206 coordination and breathings timing in a stroke cycle) was not affected by the wetsuit and neither was
207 swimming comfort in experienced triathletes.

208 During a swimming activity the different density between legs and chest leads to an inclination of the
209 body alignment on the sagittal plane of the swimmer, also known as “sinking legs”, that increases
210 resistance and reduces swimming speed⁴². The results of our study highlight the effect of wetsuit use
211 on reducing TI (~28%, >3°) and thus the frontal area presented by the swimmer to the water that has
212 an effect on the form component of active drag⁶. Toussaint et al, in their pioneer work in 1989⁶,
213 showed a 14% reduction in active drag (estimated with the Measurement Active Drag system) while
214 swimming in wetsuit condition at 1.25 m/s. Other studies instead, showed no differences due to
215 wetsuit use in active drag (measured by the perturbation method) when evaluated during a maximal
216 sprint^{8,19}. However, the speed in the wetsuit condition during a maximal sprint was higher (~5%⁸)
217 compared to the swimsuit condition and this could justify the fact that no differences were found in
218 active drag¹³. Moreover, we can hypothesize that also friction drag is decreased in wetsuit, as
219 suggested by the longer underwater phase found in the current study (~13.7%), attributable to the
220 water repellent properties of the wetsuit surface. Similarly, friction drag has been shown to decrease
221 with wetsuit, inversely to the speed, when athletes were towed in a prone position⁷. As a consequence,
222 there seems to be a direct effect of wetsuit in decreasing drag during swimming, at least in the form
223 and friction components.

224 Due to the decreased drag in wetsuit condition, the propelling proficiency seems to increase by
225 reducing stroke rate (SR) and increasing SL and SI, at the same swimming speed. Our results support
226 previous findings where open water swimmers and triathletes swimming with a wetsuit showed
227 technical adaptations that reduced SR and increased SL⁹. Although the IdC was classifiable as a catch-
228 up model in both conditions, our results showed lower percentage values in wetsuit condition
229 compared to swimsuit. The lower propulsive phases indicate a shorter period of propulsive force
230 application, thus low power generation at the same swimming speed using a wetsuit³⁶. However,
231 other studies involving triathletes or open water swimmers showed different results^{11,13,16} depending
232 on speed, duration and if swimming in a flume or in a swimming pool. It has to be pointed out that
233 most of the studies in the literature did not test subjects over a pre-set speed, leading to artefactual
234 results attributable to the higher swimming speed reached in wetsuit condition^{9,16,22}.

235 Regarding the effects of wetsuit on number of kicks, our results confirm the perceived decrease in
236 kicking frequency previously reported by the athletes using a wetsuit^{20,21} and in accordance with what
237 has already been reported during a 800 m¹⁷, but not in shorter tasks¹¹. Leg kicks have the main effect
238 of reducing TI during crawl swimming⁴³; the decrease of TI by wetsuit use brings to a consequent
239 reduction in number of kicks needed to maintain the same position in the water. Moreover, the
240 reduction of kicking frequency is profitable in both triathlon and open water races, which require
241 cycling and running after the swimming fraction in triathlon and very intensive finishing strategies in
242 long open water races^{2,22}.

243 Motor coordination, in particular IdC model, IdS value, timing of kicking and breathing, appeared
244 not to be affected by wetsuit use, indicating that aspects of motor control acting on technique are not
245 related to the suit used. An unchanged effect in kick adjustment by wetsuit use is favourable to
246 athletes during swimming in adverse environmental conditions, where waves might change the arm-
247 leg coordination related to the effects of the moving body of water²⁶. Moreover, a correct
248 synchronization of breathing-stroke has shown to be crucial to apply a great impulse of force and its
249 correctness is related to the relative swimming speed and performance level²⁵.

250 Enhancing buoyancy and decreasing drag seems to lead to a decrease of both physiological variables
251 (lower HR and number of breathings) and rates of perceived exertion (lower RPE) at the same
252 swimming speed while using a wetsuit compared to swimsuit. RPE increase throughout exercise is
253 recognized as a major feature of sensation of fatigue as well as playing a pivotal role in regulating
254 pacing during exercise⁴⁴. Moreover, it has been reported that respiratory frequency is the best
255 correlate of RPE during self-paced maximal effort exercise, irrespective of the intermittent or
256 continuous nature of the protocol⁴⁵. During a swimming activity, in particular during front-crawl, the
257 breathing action disrupts the body alignment, increasing drag and reducing SL²⁵. Interestingly, a
258 lower breathing frequency was found in more skilled swimmers compared to less skilled²⁵. The
259 current study is the first investigating the effects of wetsuit on breathing, showing a lower number of
260 breathings compared to swimsuit. The differences showed in RPE and HR are similar to what was
261 previously shown at a speed of 1.31m/s, but not at lower speeds^{13,18} or at pre-set distance^{9,12,17} or
262 time¹⁰. However, a pre-set distance or time test imply a difference in speed between swimsuit and
263 wetsuit^{9,10,12,17}, therefore lower values of RPE or HR may be expected when normalizing by speed.
264 Moreover, the pre-set speed tests were performed in a flume for 5 minutes for each trial^{13,18}, which
265 may not be long enough to detect changes in RPE and HR. Indeed, we found no differences in HR or
266 RPE during the first 200 m, but thereafter both increased in the swimsuit condition but not in the
267 wetsuit.

268 The choice of our test was to evaluate not only differences between swimsuit and wetsuit on overall
269 performance, but also how the use of wetsuit could mitigate the fatigability throughout a longer task.
270 In detail, in the swimsuit condition more variables (i.e. RPE, HR, number of strokes and breathings)
271 increased from the beginning to the end of the 7x200 m, while in the wetsuit condition only HR
272 increased during the trial with no difference in RPE, number of strokes and breathings. We found no
273 changes in stroke phases percentage during the task, while an increase in the propulsive phase was
274 found between the first and the last length of a 1500 m in wetsuit, but not in swimsuit¹⁴. However,
275 the task was conducted at maximal speed and it is unlikely that the swimming speed both between
276 conditions and between the first and last length were the same. Recently, Rois et al.²⁷ reported a
277 decreased HR in wetsuit condition compared to swimsuit while swimming in a 25°C flume for 75
278 minutes with no difference in RPE. However, the authors suggest that the increase in HR during the
279 swimsuit condition was mainly due to compensate for heat generation rather than an index of
280 intensity. Athletes were in fact swimming at an intensity of 70% of their critical velocity with a final
281 RPE of 3 that corresponds to a sub-VT1 (ventilatory threshold 1) intensity⁴⁶. Our triathletes instead
282 reported an average RPE of 5 indicating a swimming intensity between the two thresholds⁴⁶. The
283 higher intensities reported in the current study might explain the variation in technical variables (i.e.
284 number of strokes and SL), the increase of physiological (i.e. HR and number of breathings) and
285 perceptual (i.e. RPE) variables in swimsuit, contrary to the steady-state shown in the wetsuit. The
286 fatigability on biomechanical variables (i.e. decreasing SL, increasing SR, increasing kicking speed,
287 increase of IdC value but not changing the model) has been reported during a classic 7x200 m
288 incremental protocol between each repetition³⁴. In particular, these variations were evident at speeds
289 above the lactate inflection point explained by the technique reorganization to overcome increased
290 hydrodynamic drag. This confirms the higher relative intensity sustained by our triathletes while
291 swimming with a swimsuit compared to a wetsuit condition, at the same swimming speed (Figure 3).
292 The current study was the first evaluating swimming comfort in wetsuit and swimsuit during
293 swimming activity²². Contrary to expectations, no difference in comfort was found. Based on our
294 preliminary survey, triathletes reported to dislike wetsuit use mainly for upper arm discomfort during
295 swimming (82%) and that they are forced in its use by rule restrictions (82%) and by the fact that
296 opponents will use it (100%). However, there was no difference in swimming comfort with or without
297 wetsuit, probably due to their familiarization with wetsuit use, as Table 1 shows. In fact, previous
298 studies showed that pool swimmers reported a lower comfort because unfamiliar with the wetsuit use,
299 compared to triathletes¹². It is important to note that there is no clear indication in the literature on
300 the definition of familiarity of an athlete with a wetsuit²². Our study is the first reporting the numbers

301 of years each athlete has been training/competing with a wetsuit. In particular, the triathletes of the
302 current study have been regularly using wetsuit (from 2 to 10 years) in a pool or open water, in
303 addition to competitions. The current study was carried out just before the competitive season, when
304 athletes mostly utilize wetsuits in training and competition.

305

306 PRACTICAL APPLICATIONS

307

308 Swimming with a full-body wetsuit during a 7x200 m front-crawl at pre-set speed, corresponding to
309 the swimming race pace of an Olympic distance triathlon, leads to a reduction of TI and drag, at least
310 in the form and friction components and thus to a delay in fatigability. Interestingly, no changes in
311 motor coordination were found, which confirms that triathletes may utilize wetsuit also during
312 training sessions. Indeed, triathletes with experience in wetsuit use did not perceive high discomfort
313 and benefited in terms of performance and reduced fatigability by wetsuit use^{7,12,22}. Therefore, the
314 use of wetsuit is recommended also in training sessions to increase familiarization, without concerns
315 about a possible negative effect on coordination. However, the amplitude of the effects might differ
316 based on athletes (i.e. open water swimmers and triathletes, elite and recreational level, experience in
317 wetsuit use) and more studies are necessary to highlight possible differences.

318

319 Our study has some limitations. The study was conducted in an indoor swimming pool with a water
320 temperature of $28.4 \pm 0.5^\circ\text{C}$, due to the unfeasibility of cooling the water. In contrast, the athletes
321 usually compete in an open water environment where a wetsuit use is
322 physiological variables when comparing swimming in cold temperature^{15,27} to a typical pool
323 allowed only at temperatures (below $20\text{--}24.6^\circ\text{C}$ ^{3,4}). Indeed, recent studies report differences in
324 environment and also in biomechanical variables compared to open water⁴⁷. However, it seems
325 that different water temperatures (at least between 26° and 18° C) do not affect biomechanical
326 parameters¹⁵. Our aim was to evaluate the presence of fatigability in biomechanical, physiological
327 and perceptual variables during a protocol similar to a training situation.

328

329 Studies
329 conducted in an open water environment, simulating competition settings, are thus recommended²².
330 We recruited only 15 young triathletes, but of International level and with experience in wetsuit use.
331 However, four triathletes were excluded because not able to replicate the speed maintained during
332 the wetsuit session and analysis was performed on only 11 subjects. The training session protocol of
333 7x200 m front-crawl constant speed interval with 1 minute rest was designed to allow triathletes to
334 correctly perform the task and to be able to compare the variables. Secondly, it allows for in between
335 measurements- (i.e. RPE and comfort). Our main intent was to compare at the same speed the selected
336 variables but also to measure the effect of fatigue which we could obtain only by increasing the
337 number of repetitions. Further studies performing a long-continuous task are recommended, as
338 already recommended in a recent review on the topic²², to confirm our results obtained during this
339 simulated training session. Finally, the stroke and kick data were estimated by IMU sensors located
340 on the right limbs only. In the following studies, we suggest locating IMU sensors on both sides for
341 refining the estimation of technical variables.

342

343 CONCLUSIONS

344

345 Using a wetsuit during a swimming task simulating competition effort reduces the trunk incline, thus
346 drag, compared to a swimsuit at the same speed. As a consequence, the triathletes show an increased
347 SI and SL, both indexes of propelling proficiency and a lower fatigability, without modifying motor
348 coordination. The use of a wetsuit also during training sessions is recommended, to increase the
349 comfort and the positive effects on performance.

350

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353

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ID	Sex	Age (Yrs)	Height (cm)	Body mass (Kg)	Body fat (%)	Perf.	Sp. (m/s)	Tri. P. (Yrs)	Tri. T. (hrs/wk)	Swi. P. (Yrs)	Swi. T. (hrs/wk)	Swi. T. (Km/wk)	Swi. T. (n/wk)	Wetsuit Exp. (Yrs)	Wetsuit Details (thickness range)
2	M	27	183	74.90	18.5	G.P.	1.39	11	21	11	8	23	4	10	Zoot - WikiWiki (2:5)
3	F	23	165	59.97	28.9	E.Jr.	1.28	11	24	11	9	25	6	8	Huub - Astana (3:3)
5	M	19	187	73.78	15.9	E.c.Jr.	1.38	10	24	11	8	26	6	5	Zoot - WikiWiki (2:5)
6	M	16	180	64.08	12.3	N.Ch.	1.14	6	25	11	5	15	3	2	Zoot - Force 1.0 (2:5)
7	M	17	173	78.48	23.9	N.Ch.	1.25	11	25	11	6	15	4	4	Huub - Aerious II (3:5)
8	M	17	174	66.23	15.5	N.Ch.	1.25	7	21	11	9	20	5	2	Tyr - Hurricane C3 (3:5)
9	F	24	162	49.73	21.8	W.Jr.	1.29	11	27	11	6	25	6	9	Yonda - Ghost (1.5:5.5)
10	F	20	173	61.65	27.8	E.c.Jr.	1.23	11	16	11	6	13	3	6	Huub - Acara (3:5)
12	M	17	175	75.25	20.3	N.Ch.	1.25	5	20	8	7	20	5	3	Zoot - WikiWiki (2:5)
13	M	18	182	73.60	17.8	E.Y.	1.41	8	23	11	9	26	6	3	Zoot - WikiWiki (2:5)
14	F	17	169	59.00	24.3	E.Y.	1.21	10	20	11	8	23	6	2	Huub - Aegis (3:5)
	M	18.7±3.8	179.4±5.3	72.33±5.20	17.7±3.7		1.30±0.10	8.3±2.4	22.7±2.1	10.6±1.1	7.4±1.5	20.7±4.6	4.7±1.1	4.1±3.0	
	F	21.0±3.2	167.3±4.8	57.59±5.35	25.7±3.3		1.25±0.04	10.8±0.5	21.8±4.8	11.0±0.0	7.3±1.5	21.5±5.7	5.3±1.5	6.3±3.1	

Total	19.56±3.56	174.58±7.57	67.50±9.50	20.56±5.53		1.528±0.508	9.52±2.53	22.54±3.51	10.57±0.59	7.54±1.54	21.50±4.58	4.59±1.52	4.59±2.59	(2.54:5) ±(0.56:0.56)
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Table 1 – Subjects characteristics, training information and wetsuit details.

M = Male; F = Female; Perf. = Best Championship raced; G.P. = ITU Grand Prix Senior; E.Jr. = European Championships Junior; E.c.Jr. = European Cup Junior; N.Ch. = Individual National Championships Senior; E.Y. = European Championships Youth; Sp. = mean speed during Olympic distance swimming fraction; Tri. P. = Triathlon Practice; Tri. T. = Triathlon Training volume; Swi. P. = Swimming Practice; Swi. T. = Swimming Training volume; Wetsuit Exp. = Wetsuit Experience; Yrs = Years, hrs/wk = hours per week; Km/wk = Kilometers per week; n/wk = number of sessions per week; the thickness range represent the higher and lower thickness value in mm independently to the body position reported by the individual industry company.

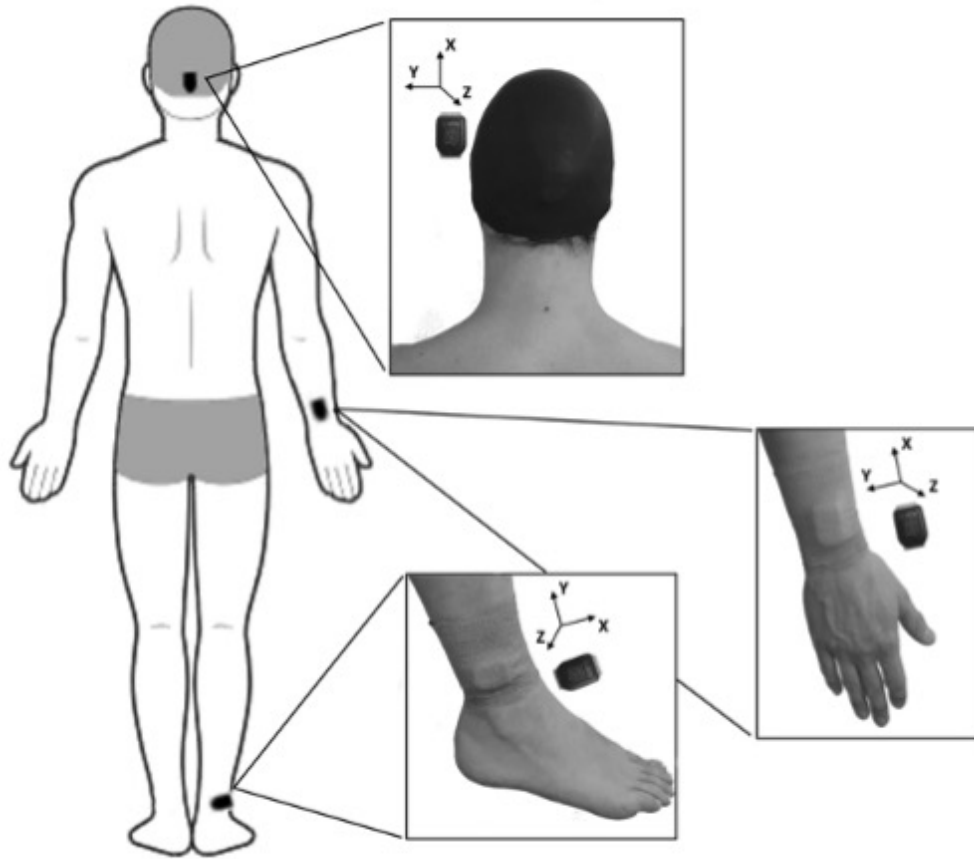


Figure 1 – Positioning of wearable inertial sensors located on the right ankle, right wrist and head with shown the alignment of axes (X, Y and Z) of the reference system.

132x118mm (96 x 96 DPI)

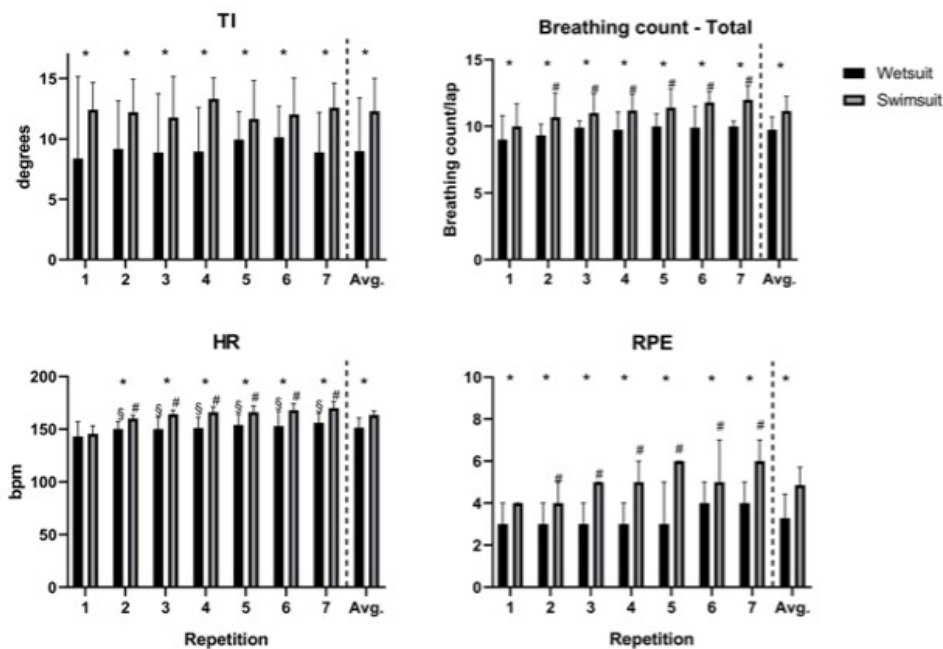


Figure 2 - Trunk incline (TI), Breathing count per lap, heart rate (HR) and rate of perceived exertion (RPE) for each repetition and average (Avg.) in wetsuit and swimsuit. Bpm = beats per minute * significantly different between conditions; § significantly different from repetition 1 in wetsuit; # significantly different from repetition 1 in swimsuit

170x119mm (96 x 96 DPI)

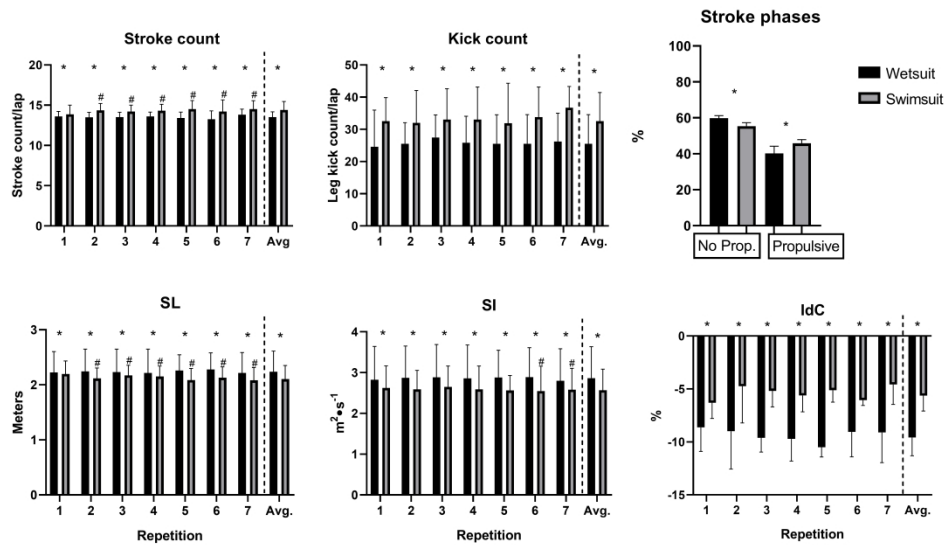


Figure 3 - Stroke (right side) count per lap, leg kick (right side) count per lap, stroke phases percentages (no propulsive= entry+catch and recovery, propulsive= pull and push), stroke length, stroke index (SI) and Index of coordination (IdC) for each repetition and average (Avg.) in wetsuit and swimsuit. * significantly different between conditions; § =significantly different from repetition 1 in wetsuit; # significantly different from repetition 1 in swimsuit

1517x896mm (96 x 96 DPI)

Detailed data

	1^ 200m	2^ 200m	3^ 200m	4^ 200m	5^ 200m	6^ 200m	7^ 200m	Avg.
Trunk incline (degrees)								
Wetsuit	8.18±9.27*	8.71±7.97*	8.35±8.82*	8.40±8.43*	9.38±7.58*	9.23±8.08*	8.48±7.52*	8.68±8.34*
Swimsuit	12.06±8.50*	11.75±7.86*	11.71±7.26*	12.91±9.10*	12.79±7.91*	11.76±8.58*	11.47±7.83*	12.07±8.20*
Underwater length (m)								
Wetsuit	3.19±0.36	3.11±0.52*	3.09±0.33*	2.95±0.48	3.14±0.21	3.23±0.42*	2.97±0.59*	3.08±0.46*
Swimsuit	2.95±0.80	2.89±0.63*	2.84±0.57*	2.80±0.48	2.79±0.68	2.76±0.59*	2.74±0.68*	2.71±0.50*
Strokes count per lap								
Wetsuit	13.7±3.2*	13.7±2.5*	13.7±2.5*	13.7±2.3*	13.5±2.0*	13.5±2.3*	13.8±2.0*	13.5±2.8*
Swimsuit	14.0±2.5*	14.7±2.4*#	14.8±2.2*#	14.8±2.2*#	14.8±2.9*#	14.8±3.0*#	14.8±2.6*#	14.4±2.6*
Stroke length (m)								
Wetsuit	2.21±0.59*	2.24±0.48*	2.21±0.48*	2.20±0.51*	2.22±0.35*	2.27±0.42*	2.22±0.34*	2.24±0.50*
Swimsuit	2.15±0.45*	2.06±0.33*#	2.04±0.37*#	2.04±0.40*#	2.04±0.39*#	2.04±0.42*#	2.04±0.39*#	2.10±0.39*
Stroke index (m²·s⁻¹)								
Wetsuit	2.80±0.94*	2.85±0.90*	2.85±0.96*	2.83±1.06*	2.84±0.91*	2.87±0.92*	2.80±0.87*	2.86±1.00*
Swimsuit	2.59±0.61*	2.56±0.45*	2.54±0.50*	2.54±0.52*	2.52±0.54*	2.51±0.58*#	2.53±0.53*#	2.57±0.64*
Index of Coordination (%)								
Wetsuit	-8.63±3.74*	-8.99±6.74*	-9.61±6.26*	-9.72±5.14*	-10.50±4.69*	-9.05±4.65*	-9.11±4.82*	-9.59±4.66*
Swimsuit	-6.30±3.25*	-4.75±5.59*	-5.18±3.64*	-5.62±3.70*	-5.12±3.46*	-6.06±4.54*	-4.58±3.81*	-5.64±3.58*
Stroke Phase – No propulsive (%)								
Wetsuit	59.26±4.11*	60.13±7.91*	59.88±8.34*	60.15±10.84*	60.13±3.98*	59.10±4.99*	59.98±5.06*	59.75±5.45*
Swimsuit	55.74±4.00*	54.23±8.33*	53.30±4.76*	55.49±4.27*	56.01±6.96*	55.36±6.40*	54.24±6.81*	55.39±5.22*
Stroke Phase - Propulsive (%)								
Wetsuit	40.74±4.11*	39.52±7.91*	40.13±8.60*	39.85±10.84*	39.87±3.98*	40.90±4.99*	40.47±4.38*	40.25±5.49*
Swimsuit	44.26±4.00*	45.77±8.33*	46.70±4.76*	44.66±4.18*	44.49±7.02*	45.58±6.40*	45.76±6.81*	45.75±5.25*
Kick count per lap								
Wetsuit	24.5±20.5*	25.8±11.3*	29.2±17.0*	25.7±18.1*	25.8±17.4*	25.5±18.0*	26.17±16.5*	25.48±12.96*
Swimsuit	32.2±15.6*	32.5±18.3*	33.0±21.4*	33.0±24.2*	33.8±23.2*	33.8±24.6*	36.7±26.8*	32.5±13.97*
Kick timing – 1^ (stroke duration %)								

Wetsuit	4.22±8.31	3.70±6.10	4.13±7.37	4.76±9.50	4.40±18.15	3.77±15.15	4.40±7.62	4.72±24.63
Swimsuit	9.79±16.05	6.17±11.10	4.25±11.19	4.79±13.12	4.48±12.35	4.63±13.71	4.99±21.11	5.76±18.14
Kick timing – 2[^] (stroke duration %)								
Wetsuit	43.33±14.80	41.10±16.81	41.24±16.08	41.90±17.04	45.16±16.92	43.67±16.43	42.05±11.90	43.84±15.19
Swimsuit	44.07±9.79	41.85±9.86	44.70±15.02	45.25±13.98	44.08±10.41	43.79±12.07	44.16±20.90	43.87±15.18
Kick timing – 3[^] (stroke duration %)								
Wetsuit	73.96±18.75	73.16±18.27	74.43±18.64	74.72±19.03	75.72±18.51	75.97±18.48	74.24±13.70	75.08±18.45
Swimsuit	75.28±13.89	74.20±14.92	72.63±17.91	73.45±18.84	73.65±18.50	72.23±19.86	72.53±23.17	75.00±15.59
Index of synchronization								
Wetsuit	0.03±0.25	-0.01±0.30	-0.01±0.21	-0.02±0.16	0.01±0.19	0.06±0.27	0.06±0.24	0.06±0.22
Swimsuit	0.01±0.20	0.02±0.10	0.01±0.25	0.01±0.13	0.01±0.25	0.00±0.10	0.01±0.10	0.01±0.12
Breathings count per lap (tot)								
Wetsuit	8.8±1.2*	9.5±1.0*	9.8±1.4*	9.7±1.2*	10.0±1.4*	9.8±0.8*	10.0±1.7*	9.8±2.0*
Swimsuit	9.7±1.8*	10.7±1.5*#	11.0±1.2*#	11.2±0.8*#	11.3±0.5*#	11.8±0.7*#	12.0±1.1*#	11.2±1.6*
Breathings count per lap - right side								
Wetsuit	4.5±5.0*	4.8±6.0*	5.2±5.4*	4.8±5.8*	3.8±6.0*	4.7±4.8*	3.3±5.2*	5.5±4.6*
Swimsuit	6.3±6.6*	6.8±7.3*	6.2±7.42*	6.7±7.8*	7.7±8.8*	7.0±7.8*	6.8±8.6*	7.7±7.1*
Breathings count per lap - left side								
Wetsuit	3.2±3.4	3.5±4.1	3.0±3.9	3.3±3.3	2.8±4.5	3.2±2.9	3.7±4.8	3.2±3.2
Swimsuit	3.2±4.8	2.3±5.3	3.3±5.0	3.5±5.6	2.2±5.6	3.3±5.0	3.2±5.1	2.8±4.6
Stroke-breathing ratio								
Wetsuit	1.45±0.45	1.33±0.49*	1.33±0.32*	1.37±0.38*	1.35±0.38*	1.30±0.45*	1.29±0.42*	1.38±0.43*
Swimsuit	1.35±0.48	1.36±0.34*#	1.31±0.26*#	1.24±0.28*#	1.27±0.25*#	1.23±0.23*#	1.13±0.27*#	1.28±0.32*
Breathing timing - right side (stroke duration %)								
Wetsuit	84.40±9.13	86.60±8.34	85.25±9.28	84.30±6.96	83.90±8.75	83.30±8.58	83.60±8.88	86.41±9.05
Swimsuit	84.55±4.37	84.70±8.17	84.00±7.73	83.80±7.88	83.80±8.55	84.60±8.28	84.90±7.76	85.16±8.10
Breathing timing - left side (stroke duration %)								
Wetsuit	35.00±5.50	34.70±7.30	35.20±5.30	34.50±6.93	34.62±7.80	35.70±8.71	34.47±9.10	34.52±7.38
Swimsuit	33.08±9.60	31.75±11.30	31.48±10.60	32.76±11.80	33.98±12.30	32.88±12.30	31.14±13.50	33.27±9.85
Heart rate (bpm)								
Wetsuit	141.5±16.0	149.5±19.3*§	149.0±20.8*§	151.0±15.0*§	153.0±19.0*§	152.0±19.3*§	155.5±16.8*§	151.4±17.3*

Swimsuit	149.5±11.5	161.5±10.5*#	164.5±7.8*#	166.5±7.5*#	166.0±11.3*#	168.5±10.0*#	170.0±11.3*#	164.2±8.6*
Rate of perceived exertion (CR-10)								
Wetsuit	3.0±2.0*	3.0±2.0*	3.0±1.5*	3.0±1.0*	3.0±2.5*	4.0±2.5*	4.0±2.0*	3.3±1.9*
Swimsuit	4.0±1.0*	4.0±2.0*#	5.0±1.0*#	5.0±2.0*#	6.0±2.0*#	5.0±3.0*	6.0±4.0*#	4.9±2.0*
Swimming comfort (from -5 to +5)								
Wetsuit	-1.0±5.0	0.0±3.0	0.0±2.0	1.0±2.0	0.0±2.0	0.0±2.0	0.0±2.0	0.1±1.9
Swimsuit	0.0±2.0	1.0±1.0	1.0±2.0	1.0±2.0	1.0±2.0	1.0±4.0	1.0±4.0	0.7±2.0

Measures of each repetition and average in wetsuit and swimsuit conditions. Median±interquartile range

* = significant different between conditions; [§] = significant different between repetition 1 in Wet; # = significant different between repetition 1 in Swi

Statistical analysis results: Between conditions

Friedman(13,11)

TI	IdC	Stroke Phase – No Propulsive	Stroke Phase - Propulsive	HR	RPE	Swimming Comfort
X ² =85.565, p=.000*, W=.658	X ² =97.443, p=.000*, W=.681	X ² =70.984, p=.000*, W=.496	X ² =67.301, p=.000*, W=.471	X ² =72.507, p=.000*, W=.797	X ² =82.779, p=.000*, W=.579	X ² =16.853, p=.206, W=.118

Friedman(13,10)

Underwater length	Stroke count	SL	SI	Kick count	Kick Timing – 1 [^]	Kick Timing – 2 [^]	Kick Timing – 3 [^]	IdS
X ² =30.397, p=.004*, W=.334	X ² =65.752, p=.000*, W=.723	X ² =70.008, p=.000*, W=.769	X ² =66.843, p=.00, W=.735	X ² =71.819, p=.000*, W=.789	X ² =8.400, p=.817, W=.162	X ² =4.192, p=.989, W=.046	X ² =3.400, p=.996, W=.033	X ² =6.820, p=.911, W=.087
Breathing count - Total	Breathing count – right side	Breathing count – left side	Stroke-Breathing count ratio	Breathing Timing - right side	Breathing Timing - left side			
X ² =74.622, p=.000*, W=.820	X ² =50.882, p=.000*, W=.435	X ² =9.600, p=.726, W=.082	X ² =57.031, p=.000*, W=.627	X ² =19.635, p=.105, W=.189	X ² =25.440, p=.020*, W=.280			

Wilcoxon (11)

Mean difference, coefficient intervals 95% and delta %

Pearson’s r thresholds: .1 small (S), .3 moderate (M), .5 large (L), .7 very large (VL), .9 extremely large (EL)¹⁹

1 [^] 200m	2 [^] 200m	3 [^] 200m	4 [^] 200m	5 [^] 200m	6 [^] 200m	7 [^] 200m	Avg.
Trunk incline							

Z=-1.956, p=.050*, r=.852 ^{VL}	Z=-2.667, p=.008*, r=.929 ^{EL}	Z=-2.224, p=.026*, r=.882 ^{VL}	Z=-2.803, p=.005*, r=.933 ^{EL}	Z=-2.803, p=.005*, r=.963 ^{EL}	Z=-2.803, p=.005*, r=.976 ^{EL}	Z=-2.803, p=.005*, r=.962 ^{EL}	Z=-2.223, p=.005*, r=.913 ^{EL}
1.5, [0.5 2.4], 32.4%	1.0, [0.3 1.7], 12,3%	2.1, [0.7 3.6], 20.5%	2.1, [0.7 3.5], 21.6%	3.3, [1.1 5.5], 29.7%	3.2, [1.1 5.4], 30,3%	3.2, [1.0 5.3], 27.6%	3.5, [1.2 5.9], 30.8%
Index of Coordination							
Z=-2.934, p=.003*, r=.857 ^{VL}	Z=-2.936, p=.003*, r=.887 ^{VL}	Z=-2.934, p=.003*, r=.886 ^{VL}	Z=-2.934, p=.003*, r=.874 ^{VL}	Z=-2.936, p=.003*, r=.867 ^{VL}	Z=-2.936, p=.003*, r=.929 ^{EL}	Z=-2.934, p=.003*, r=.857 ^{VL}	Z=-2.934, p=.003*, r=.949 ^{EL}
3.1, [1.0 5.1], -7.1%	4.4, [1.4 7.3], -143.3%	3.5, [1.2 5.9], -98.4%	4.0, [1.3 6.7], -84.5%	4.5, [1.5 7.5], -77.5%	4.0, [1.3 6.7], -131.5%	4.8, [1.6 8.0], -65.0%	4.0, [1.3 6.7], -124.6%
Stroke phase – No propulsive							
Z=-2.223, p=.026*, r=.542 ^L	Z=-2.934, p=.003*, r=.829 ^{VL}	Z=-2.756, p=.006*, r=.796 ^{VL}	Z=-2.667, p=.008*, r=.754 ^{VL}	Z=-2.845, p=.004*, r=.490 ^M	Z=-2.134, p=.010*, r=.629 ^L	Z=-2.134, p=.033*, r=.714 ^{VL}	Z=-2.934, p=.003*, r=.889 ^{VL}
2.9, [1.0 4.9], 6.4%	5.9, [1.9 9.9], 13.0%	3.8, [1.2 6.3], 8.3%	4.4, [1.4 7.3], 9.7%	5.5, [1.8 9.2], 11.5%	3.1, [1.0 5.2], 6.8%	4.6, [1.5 7.7], 9.6%	4.3, [1.4 7.2], 9.6%
Stroke Phase – Propulsive							
Z=-2.223, p=.026*, r=.516 ^L	Z=-2.934, p=.003*, r=.838 ^{VL}	Z=-2.401, p=.016*, r=.700 ^{VL}	Z=-2.667, p=.003*, r=.646 ^L	Z=-2.845, p=.004*, r=.522 ^L	Z=-2.134, p=.033*, r=.623 ^L	Z=-2.667, p=.008*, r=.725 ^{VL}	Z=-2.934, p=.003*, r=.857 ^{VL}
-2.9, [- 1.0 -4.8], -5.4%	-.57, [-1.9 -9.5], -10.6%	-4.0, [-1.3 -6.7], -7.4%	-4.1, [-1.3 -6.8], -7.4%	-5.7, [-1.9 -9.5], -11.0%	-3.0, [-1.0 -5.0], -5.5%	-4.5, [-1.5 -7.6], -8.8%	-4.3, [-1.4 -7.1], -7.8%
HR							
Z=-1.051, p=.293, r=.383 ^M	Z=-2.403, p=.016*, r=.672 ^L	Z=-2.805, p=.005*, r=.631 ^L	Z=-2.550, p=.011*, r=.537 ^L	Z=-2.578, p=.010*, r=.560 ^L	Z=-2.763, p=.006*, r=.556 ^L	Z=-2.758, p=.006*, r=.578 ^L	Z=-2.312, p=.021*, r=.582 ^L
3.0,	9.5,	12.0,	12.4,	11.6,	12.5,	12.9,	10.3,

[1.0 5.0], 1.6%	[3.1 15.8], 5.9%	[3.9 20.1] 7.2%	[4.1 20.7] 7.3%	[3.8 19.5] 6.9%	[4.1 21.0] 7.3%	[4.2 21.6] 7.5%	[3.4 17.2] 6.2%
RPE							
Z=-2.456, p=.014*, r=.910 ^{EL}	Z=-2.699, p=.007*, r=.841 ^{VL}	Z=-2.701, p=.007*, r=.805 ^{VL}	Z=-3.035, p=.002*, r=.928 ^{EL}	Z=-2.831, p=.005*, r=.807 ^{VL}	Z=-2.965, p=.003*, r=.860 ^{VL}	Z=-2.836, p=.005*, r=.863 ^{VL}	Z=-2.934, p=.003*, r=.912 ^{EL}
0.8, [0.3 1.3], 21.1%	1.2, [0.4 2.0], 28.5%	1.3, [0.4 2.2], 29.8%	1.6, [0.5 2.7], 36.5%	1.8, [0.6 3.0], 35.8%	1.7, [0.6 2.8], 34.3%	1.8, [0.6 3.0], 32.2%	1.5, [0.5 2.4], 32.4%

Wilcoxon (10)

Mean difference, coefficient intervals 95% and delta %

Pearson's r thresholds: .1 small (S), .3 moderate (M), .5 large (L), .7 very large (VL), .9 extremely large (EL)¹⁹

1^ 200m	2^ 200m	3^ 200m	4^ 200m	5^ 200m	6^ 200m	7^ 200m	Avg.
Underwater length							
Z=-1.836, p=.066, r=.248 ^S	Z=-2.497, p=.013*, r=.552 ^L	Z=-2.073, p=.038*, r=.550 ^L	Z=-1.125, p=.260, r=.382 ^S	Z=-1.820, p=.069, r=.738 ^{VL}	Z=-2.547, p=.011*, r=.750 ^{VL}	Z=-2.521, p=.012*, r=.619 ^L	Z=-2.395, p=.017*, r=.672 ^L
-0.3, [-.1 -.5], -13.1%	-0.4, [-.1 -.7], -15.8%	-0.4, [-.1 -.7], -16.0%	-0.3, [-.1 -.5], -13.1%	-0.3, [-.1 -.6], -13.8%	-0.4, [-.1 -.7], -15.6%	-0.4, [-.1 -.7], -14.2%	-0.4, [-.1 -.6], -14.7%
Strokes count per lap							
Z=-2.552, p=.011*, r=.935 ^{EL}	Z=-2.666, p=.008*, r=.932 ^{EL}	Z=-2.521, p=.012*, r=.895 ^{VL}	Z=-2.429, p=.015*, r=.807 ^{VL}	Z=-2.366, p=.018*, r=.775 ^{VL}	Z=-2.668, p=.008*, r=.863 ^{VL}	Z=-2.521, p=.012*, r=.875 ^{VL}	Z=-2.803, p=.005*, r=.926 ^{EL}
0.9, [0.3 1.6], 6.8%	1.3, [0.4 2.2], 9.3%	1.4, [0.4 2.3], 9.8%	1.4, [0.4 2.3], 9.7%	1.3, [0.4 2.2], 8.8%	1.6, [0.4 2.7], 10.9%	1.6, [0.4 2.7], 9.8%	1.3, [0.4 2.3], 9.4%
Stroke length							
Z=-2.497, p=.013*, r=.943 ^{EL}	Z=-2.803, p=.005*, r=.944 ^{EL}	Z=-2.666, p=.008*, r=.917 ^{EL}	Z=-2.666, p=.008*, r=.906 ^{EL}	Z=-2.524, p=.012*, r=.793 ^{VL}	Z=-2.666, p=.008*, r=.872 ^{VL}	Z=-2.521, p=.012*, r=.889 ^{VL}	Z=-2.803, p=.005*, r=.940 ^{EL}

-0.1, [.0 -.2], -6.4%	-0.2, [-.1 -.3], -9.2%	-0.2, [-.1 -.4], -9.9%	-0.2, [-.1 -.4], -10.1%	-0.2, [-.1 -.3], -8.8%	-0.2, [-.1 -.4], -11.1%	-0.2, [-.1 -.4], -10.0	-0.2, [-.1 -.3], -9.3%
Stroke index							
Z=-2.803, p=.005*, r=.975 ^{EL}	Z=-2.701, p=.007*, r=.968 ^{EL}	Z=-2.666, p=.008*, r=.950 ^{EL}	Z=-2.666, p=.008*, r=.967 ^{EL}	Z=-2.521, p=.012*, r=.904 ^{EL}	Z=-2.670, p=.008*, r=.942 ^{EL}	Z=-2.521, p=.012*, r=.946 ^{EL}	Z=-2.803, p=.005*, r=.970 ^{EL}
-0.3, [-.1 -.5], -9.6%	-0.3, [-.1 -.5], -10.6%	-0.3, [-.1 -.5], -10.9%	-0.3, [-.1 -.5], -10.9%	-0.3, [-.1 -.4], -9.8%	-0.3, [-.1 -.6], -11.7%	-0.4, [-.1 -.6], -11.4%	-0.3, [-.1 -.5], -10.6%
Leg kicks count per lap							
Z=-2.803, p=.005*, r=.911 ^{EL}	Z=-2.805, p=.005*, r=.895 ^{VL}	Z=-2.666, p=.008*, r=.952 ^{EL}	Z=-2.666, p=.008*, r=.843 ^{VL}	Z=-2.521, p=.012*, r=.920 ^{EL}	Z=-2.666, p=.008*, r=.904 ^{EL}	Z=-2.366, p=.018*, r=.855 ^{VL}	Z=-2.803, p=.005*, r=.915 ^{EL}
6.3, [1.8 10.7], 21.6%	7.6, [2.2 13.1], 25.1%	6.6, [1.9 11.4], 22.2%	8.1, [2.3 13.9], 25.3%	7.6, [2.2 13.0], 24.0%	8.3, [2.4 14.3], 26.9%	8.2, [2.3 14.0], 22.0%	6.8, [1.9 11.7], 17.4%
Breathings count per lap (tot)							
Z=-2.805, p=.005*, r=.965 ^{EL}	Z=-2.803, p=.005*, r=.901 ^{EL}	Z=-2.524, p=.012*, r=.907 ^{EL}	Z=-2.666, p=.008*, r=.984 ^{EL}	Z=-2.521, p=.012*, r=.766 ^{VL}	Z=-2.668, p=.008*, r=.909 ^{EL}	Z=-2.521, p=.012*, r=.919 ^{EL}	Z=-2.803, p=.005*, r=.963 ^{EL}
1.0, [0.3 1.7], 9.7%	1.7, [0.5 2.9], 15.1%	1.6, [0.5 2.7], 14.3%	1.8, [0.5 3.0], 15.9%	1.9, [0.5 3.2], 15.5%	2.0, [0.6 3.5], 17.4%	2.3, [0.6 3.9], 17.3%	1.7, [0.5 2.9], 15.1%
Breathings count per lap – right side							
Z=-2.499, p=.012*, r=.971 ^{EL}	Z=-2.670, p=.008*, r=.959 ^{EL}	Z=-2.521, p=.012*, r=.966 ^{EL}	Z=-2.255, p=.024*, r=.938 ^{EL}	Z=-2.075, p=.038*, r=.923 ^{EL}	Z=-2.552, p=.011*, r=.955 ^{EL}	Z=-2.192, p=.028*, r=.524 ^L	Z=-2.599, p=.009*, r=.947 ^{EL}
1.1, [0.3 1.9], 13.8%	2.0, [0.6 3.4], 24.8%	1.6, [0.5 2.8], 21.1%	1.5, [0.4 2.6], 11.2%	1.9, [0.5 3.2], 16.2%	2.2, [0.6 3.8], 21.9%	3.6, [1.0 6.1], 4.6%	1.9, [0.5 3.3], 20.6%
Stroke-breathing ratio							

Z=-1.376, p=.169, r=.938 ^{EL}	Z=-2.191, p=.028*, r=.905 ^{EL}	Z=-2.100, p=.036*, r=.934 ^{EL}	Z=-2.249, p=.015*, r=.970 ^{EL}	Z=-2.521, p=.012*, r=.915 ^{EL}	Z=-2.666, p=.008*, r=.928 ^{EL}	Z=-2.521, p=.012*, r=.925 ^{EL}	Z=-2.701, p=.007*, r=.971 ^{EL}
0.0, [0.0 -.1], -3.4%	-0.1, [0.0 -.2], -7.2%	-0.2, [-.1 -.4], -5.7%	-0.2, [-.1 -.4], -7.3%	-0.4, [-.1 -.7], -8.3%	-0.2, [-.1 -.4], -8.3%	-0.2, [0.0 -.3], 1.4%	-0.1, [0.0 -.2], -6.8%
Timing Breathing - left side							
Z=-0.560, p=.575, r=.832 ^{VL}	Z=-1.820, p=.069, r=.927 ^{EL}	Z=-1.040, p=.310, r=.858 ^{VL}	Z=-1.521, p=.128, r=.908 ^{EL}	Z=-1.014, p=.310, r=.893 ^{VL}	Z=-1.521, p=.128, r=.885 ^{VL}	Z=-1.183, p=.237, r=.874 ^{VL}	Z=-1.400, p=.161, r=.882 ^{VL}
-3.4, [- 1.0 -5.9], -2.4%	-1.5, [-.4 -2.5], -4.8%	-1.0, [-.3 -1.8], -4.2%	-1.9, [-.5 -3.3], -6.2%	-4.0, [-1.1 -6.9], -3.2%	-5.7, [-1.6 -9.8], -7.1%	-1.7, [-.5 -2.8], -6.9%	-4.3, [-1.2 -7.4], -4.7%

Statistical analysis results: Within condition

Friedman (6,11)

	TI	IdC	Stroke phase – No propulsive	Stroke phase – Propulsive	HR	RPE	Swimming Comfort
Wetsuit	X ² =4.671, p=.587, W=.078	X ² =2.104, p=.910, W=.032	X ² =6.000, p=.423, W=.091	X ² =5.961, p=.428, W=.090	X ² =38.278, p=.000*, W=.709	X ² =9.996, p=.125, W=.151	X ² =2.086, p=.912, W=.032
Swisuit	X ² =1.364, p=.968, W=.021	X ² =7.776, p=.255, W=.118	X ² =7.013, p=.320, W=.106	X ² =9.000, p=.174, W=.136	X ² =52.069, p=.000*, W=.868	X ² =17.687, p=.007*, W=.268	X ² =1.789, p=.938, W=.027

Friedman (6,10)

	Underwater length	Stroke count	SL	SI	Kick count	Kick Timing – 1 [^]	Kick Timing – 2 [^]	Kick Timing – 3 [^]	IdS
Wetsuit	X ² =2.238, p=.897, W=.041	X ² =5.165, p=.523, W=.096	X ² =5.676, p=.460, W=.105	X ² =4.665, p=.587, W=.086	X ² =3.675, p=.721, W=.068	X ² =4.393, p=.624, W=.183	X ² =4.821, p=.567, W=.100	X ² =7.238, p=.299, W=.134	X ² =5.171, p=.522, W=.108
Swisuit	X ² =7.766, p=.256, W=.162	X ² =32.547, p=.000*, W=.678	X ² =28.828, p=.000*, W=.601	X ² =15.215, p=.019*, W=.317	X ² =19.005, p=.004*, W=.396	X ² =11.265, p=.081, W=.268	X ² =5.839, p=.441, W=.122	X ² =1.071, p=.893, W=.022	X ² =4.598, p=.596, W=.096
	Breathing count - total	Breathing count – right side	Breathing count – left side	Stroke – Breathing count ratio	Breathing Timing - right side	Breathing Timing - left side			
Wetsuit	X ² =7.936, p=.243, W=.147	X ² =4.348, p=.630, W=.072	X ² =2.573, p=.860, W=.043	X ² =8.609, p=.197, W=.159	X ² =12.192, p=.058, W=.226	X ² =4.489, p=.611, W=.094			

Swisuit	X ² =35.739, p=.000*, W=.745	X ² =7.852, p=.249, W=.145	X ² =3.869, p=.694, W=.072	X ² =31.255, p=.000*, W=.651	X ² =3.767, p=.708, W=.070	X ² =8.000, p=.238, W=.190
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Wilcoxon (11)

Mean difference, coefficient intervals 95% and delta %

Pearson’s r thresholds: .1 small (S), .3 moderate (M), .5 large (L), .7 very large (VL), .9 extremely large (EL)¹⁹

	1-2	1-3	1-4	1-5	1-6	1-7
HR						
Wetsuit	Z=-2.552, p=.011*, r=.973 ^{EL}	Z=-2.673, p=.008*, r=.986 ^{EL}	Z=-2.677, p=.007*, r=.968 ^{EL}	Z=-2.668, p=.008*, r=.967 ^{EL}	Z=-2.668, p=.008*, r=.914 ^{EL}	Z=-2.668, p=.008*, r=.952 ^{EL}
	5.3, [1.7 8.9], 3.8%	6.7, [2.2 11.1], 4.6%	8.2, [2.7 13.7], 5.7%	9.6, [3.1 16.0], 6.6%	10.7, [3.5 17.8], 7.6%	11.4, [3.8 19.1], 8.2%
Swimsuit	Z=-2.805, p=.005*, r=.761 ^{VL}	Z=-2.807, p=.005*, r=.853 ^{VL}	Z=-2.803, p=.005*, r=.823 ^{VL}	Z=-2.805, p=.005*, r=.749 ^{VL}	Z=-2.805, p=.005*, r=.781 ^{VL}	Z=-2.807, p=.005*, r=.794 ^{VL}
	12.9, [4.2 21.6], 10.2%	17.1, [5.8 29.6], 13.6%	19.8, [6.5 33.1], 15.2%	20.3, [6.7 33.9], 15.8%	22.5, [7.4 37.6], 17.2%	23.6, [7.7 39.5], 18.0%
RPE						
Swimsuit	Z=-2.236, p=.025*, r=.935 ^{EL}	Z=-2.268, p=.023*, r=.713 ^{VL}	Z=-2.460, p=.014*, r=.532 ^L	Z=-2.441, p=.015*, r=.449 ^M	Z=-1.904, p=.057, r=.058 ^S	Z=-2.328, p=.020*, r=.152 ^S
	0.5, [.1 .8], 20.8%	0.8, [0.3 1.3], 42.2%	1.0, [0.3 1.7], 58.1%	1.4, [0.5 2.4], 76.5%	1.4, [0.4 2.3], 84.5%	1.8, [0.6 3.0], 99.6%

Wilcoxon (10)

Mean difference, coefficient intervals 95% and delta %

Pearson's r thresholds: .1 small (S), .3 moderate (M), .5 large (L), .7 very large (VL), .9 extremely large (EL)¹⁹

	1-2	1-3	1-4	1-5	1-6	1-7
Strokes count per lap						
Swimsuit	Z=-2.527, p=.012*, r=.990 ^{EL}	Z=-2.384, p=.017*, r=.959 ^{EL}	Z=-2.527, p=.012*, r=.958 ^{EL}	Z=-2.243, p=.025*, r=.952 ^{EL}	Z=-2.692, p=.007*, r=.978 ^{EL}	Z=-2.670, p=.008*, r=.962 ^{EL}
	0.3, [0.1 0.6], 2.5%	0.4, [0.1 0.7], 3.0%	0.5, [0.1 0.9], 3.7%	0.6, [0.2 1.0], 4.0%	0.7, [0.2 1.2], 4.9%	0.8, [0.2 1.3], 5.7%
Stroke length						
Swimsuit	Z=-2.142, p=.032*, r=.982 ^{EL}	Z=-2.196, p=.028*, r=.947 ^{EL}	Z=-2.524, p=.012*, r=.962 ^{EL}	Z=-2.103, p=.035*, r=.942 ^{EL}	Z=-2.668, p=.008*, r=.973 ^{EL}	Z=-2.677, p=.007*, r=.973 ^{EL}
	-0.1, [0.0 -.1], -2.2%	-0.1, [0.0 -.1], -2.6	-0.1, [0.0 -.1], -3.5	-0.1, [0.0 -.1], -3.5	-0.1, [0.0 -.2], -4.5	-0.1, [0.0 -.2], -5.1
Stroke index						
Swimsuit	Z=-0.766, p=.443, r=.980 ^{EL}	Z=-0.534, p=.594, r=.969 ^{EL}	Z=-1.719, p=.086, r=.983 ^{EL}	Z=-1.192, p=.233, r=.966 ^{EL}	Z=-2.103, p=.035*, r=.987 ^{EL}	Z=-2.429, p=.015*, r=.983 ^{EL}
	0.0 [0.0 0.0], -0.7%	0.0 [0.0 0.0], -0.6%	0.0 [0.0 -.1], -1.7%	0.0 [0.0 -.1], -1.9%	0.0 [0.0 -.1], -2.4%	0.0 [0.0 -.1], -3.1%
Leg kicks count per lap						
Swimsuit	Z=-1.785, p=.074, r=.941 ^{EL}	Z=-1.836, p=.066, r=.984 ^{EL}	Z=-1.838, p=.066, r=.961 ^{EL}	Z=-1.544, p=.123, r=.977 ^{EL}	Z=-1.719, p=.086, r=.958 ^{EL}	Z=-1.836, p=.066, r=.911 ^{EL}
	0.6, [0.2 1.1], 1.9%	1.2, [0.3 2.1], 3.9%	1.6, [0.5 2.7], 4.6%	1.5, [0.4 2.5], 4.0%	1.8, [0.5 3.0], 5.0%	2.1, [0.6 3.6], 6.0%
Breathing count per lap						

Swimsuit	Z=-2.810, p=.005*, r=.978 ^{EL}	Z=-2.668, p=.008*, r=.974 ^{EL}	Z=-2.677, p=.007*, r=.968 ^{EL}	Z=-2.371, p=.018*, r=.881 ^{VL}	Z=-2.670, p=.008*, r=.938 ^{EL}	Z=-2.666, p=.008*, r=.924 ^{EL}
	0.7, [0.2 1.3], 7.6%	1.0, [0.3 1.8], 10.8%	1.1, [0.3 1.9], 11.5%	1.3, [0.3 1.9], 11.5%	1.5, [0.4 2.5], 15.4%	1.7, [0.5 2.9], 17.1%
Stroke-breathing ratio						
Swimsuit	Z=-2.395, p=.017*, r=.968 ^{EL}	Z=-2.666, p=.008*, r=.966 ^{EL}	Z=-2.666, p=.008*, r=.970 ^{EL}	Z=-2.521, p=.012*, r=.921 ^{EL}	Z=-2.666, p=.008*, r=.944 ^{EL}	Z=-2.666, p=.008*, r=.943 ^{EL}
	-0.1, {0.0 -.1}, -4.6	-0.1, [0.0 -.2], -6.8%	-0.1, [0.0 -.2], -6.8%	-0.1, [0.0 -.2], -7.8%	-0.1, [0.0 -.2], -8.6%	-0.1, [0.0 -.2], -9.3%