

Alma Mater Studiorum Università di Bologna
Archivio istituzionale della ricerca

Wetsuit Use during Open Water Swimming. Does It "suit" Everybody? A Narrative Review

This is the final peer-reviewed author's accepted manuscript (postprint) of the following publication:

Published Version:

Quagliarotti C., Cortesi M., Gatta G., Bonifazi M., Zamparo P., Baldassarre R., et al. (2021). Wetsuit Use during Open Water Swimming. Does It "suit" Everybody? A Narrative Review. INTERNATIONAL JOURNAL OF SPORTS PHYSIOLOGY AND PERFORMANCE, 16(9), 1217-1224 [10.1123/IJSP.2020-0808].

Availability:

This version is available at: <https://hdl.handle.net/11585/855257> since: 2023-11-22

Published:

DOI: <http://doi.org/10.1123/IJSP.2020-0808>

Terms of use:

Some rights reserved. The terms and conditions for the reuse of this version of the manuscript are specified in the publishing policy. For all terms of use and more information see the publisher's website.

This item was downloaded from IRIS Università di Bologna (<https://cris.unibo.it/>).
When citing, please refer to the published version.

(Article begins on next page)

This is the final peer-reviewed accepted manuscript of:

Quagliarotti C, Cortesi M, Gatta G, Bonifazi M, Zamparo P, Baldassarre R, et al. Wetsuit Use During Open Water Swimming. Does It “Suit” Everybody? A Narrative Review. *International Journal of Sports Physiology and Performance*. 2021 Jul 26;16(9):1217–24.

The final published version is available online at:

<https://dx.doi.org/10.1123/IJSP.2020-0808>

Terms of use:

Some rights reserved. The terms and conditions for the reuse of this version of the manuscript are specified in the publishing policy. For all terms of use and more information see the publisher's website.

This item was downloaded from IRIS Università di Bologna (<https://cris.unibo.it/>)

When citing, please refer to the published version.

1 ABSTRACT

2 **Purpose:** Although wearing a wetsuit while swimming, when permitted, is primarily for safety
3 reasons (*i.e.* to protect against hypothermia), changes in buoyancy, biomechanics and
4 exercise performance have been reported. This narrative review covers the benefits of different
5 wetsuit models on performance in swimming and triathlon. **Methods:** A computer search of online
6 databases was conducted to locate relevant published research until March 2021. After the
7 screening process, 17 studies were selected for analysis. **Results:** Most
8 of the selected studies involved pool swimmers or triathletes completing short- or middle-distances
9 in a pool whilst using a full or a long-sleeveless wetsuit. Swimming with wetsuit
10 elicited significant improvements in performance (maximum 11%), mainly by decreasing drag,
11 energy cost, buoyancy and by affecting technique. Different rates of change in each factor were
12 found according to swimming ability and wetsuit model. Additionally, wearing a wetsuit was often
13 rated as uncomfortable by athletes. **Conclusion:** Although improvement in swimming performance
14 by wearing a wetsuit has been reported in the literature, the amplitude of the improvement remains
15 questionable. The enhancement in swimming performance is attributable merely to improvements
16 in propulsion proficiency and buoyancy, as well as a reduction in drag. The extent to which athletes
17 are familiar with the use of a wetsuit, their swimming ability, and the wetsuit model may play
18 important roles in this improvement. More studies simulating competition
19 and comparing elite versus non elite athletes are needed.

20
21 **Keywords:** Triathletes, pool swimmers, performance, stroke technique, drag

22

23 INTRODUCTION

24 Depending on water temperature, swimming distance and age group¹, both triathletes and open
25 water swimmers can compete with wetsuit. In general, triathletes are more familiar
26 with wetsuits use than open water swimmers. The use of wetsuits has been introduced in triathlon
27 races already in 1989², whereas wetsuit use by open water swimmers was only legalized by the
28 International Swimming Federation in 2017³ (Table 1). Regulations on wetsuit use, as thermal
29 protection⁴⁻⁶ in low water temperatures, were firstly provided for safety reasons⁷⁻⁹. Wetsuits are
30 made of neoprene (*i.e.* synthetic rubber that contains small bubbles of gas) that reduces convective
31 heat loss and provides varying degrees of thermal insulation¹⁰. Wearing a wetsuit has been shown to
32 maintain core body temperature in water temperatures between 12 and 29.5°C^{6,7,11,12}.

33

34 Table 1

35

36 The use of wetsuit can change buoyancy and the biomechanics of swimming,
37 with an associated enhancement of performance (Figure 1). But these effects are differentially
38 related to the characteristics of the athlete, to individual swimming capacity, and to the wetsuit
39 model that is utilised^{8,13,14}. Therefore, there is still a need to determine the extent to which these
40 factors influence the effects of wetsuit use in triathlon and open water swimming. This narrative
41 review covers the scientific literature relating to the potential performance (*i.e.* physiological,
42 biomechanical or technical) benefits to triathletes and open water swimmers of wearing a wetsuit,
43 according to the model of wetsuit that is used.

44

45

46 METHODS

47 *Literature search*

48 Computer searches of the PubMed, SPORTDiscus, Web of Science and Scopus online databases
49 were conducted to locate relevant research published until and including March 2021. To locate
50 relevant studies, we searched for the following words in any part of the published papers (*i.e.* title,
51 keywords, abstract): “swimming” AND “wetsuit” OR “wet-suit” OR “wet suit”. The initial
52 literature search identified 388 articles.

53

54 *Screening process and Inclusion criteria*

55 The article screening process was then conducted as follows: i) duplicates were deleted; ii) those
56 with abstracts that were not pertinent were discarded; iii) integral reading of the remaining studies
57 was conducted to exclude those not related to our research topic. All the
58 reference sections of the selected articles were read to find other articles. The inclusion criteria for
59 the studies that are included by this review were: (a) studies published in English; (b) studies with
60 full texts available; (c) studies including only athletes. Table 2 summarizes the methodological
61 approach of the 17 studies that were selected for this review.

62

63 Table 2

64

65 **RESULTS**

66 Figure 1

67

68 ***Drag***

69 The smooth surface of the wetsuit leads to a reduction in friction drag, while the lower specific
70 gravity of the neoprene increases the buoyancy of the swimmer, elicits a decrease in the frontal area
71 and thus a decrease in pressure drag¹⁵. Moreover, the increase in swimming speed seems to be
72 inversely related to the reduction in both active (estimated by the Measurement Active Drag
73 system)¹⁵ and passive (estimated by the towing method)¹⁶ drags (-16.1% and -22% at 1.1 m·s⁻¹ and
74 by -12.1% and -10% at 1.5 m·s⁻¹, respectively). However, during a maximal 30m test¹⁷ neither drag
75 coefficient nor active drag force (estimated by the velocity perturbation method) were shown to
76 differ between the wetsuit and non-wetsuit condition. This may have been, as the authors
77 themselves stated, because the study methodology was insufficiently sensitive to detect the flotation
78 effect and the decrease in resistance that is provided by wearing a wetsuit. Although we are aware
79 that the method utilized to measure drag may bring to different conclusions¹⁸, it is beyond the scope
80 of this review to discuss these methods. Drag decrease did not differ between males and females
81 wearing a wetsuit¹⁵.

82

83 ***Propulsion proficiency***

84

85 *Stroke technique*

86 During a fixed time or distance swimming, both stroke length (SL) and stroke rate (SR), and
87 consequently stroke index (SI) (equal to speed*SL), have been shown to be increased^{1,7,13,14,16,19,20}
88 or unaffected^{1,13,14,21} by wetsuit use, as compared to the control condition. Although no difference in
89 the index of coordination (inter-arm coordination, IdC) was found in subjects wearing a wetsuit at
90 different speeds^{13,20}, a significant increase (+21.88%) in the IdC was found at 1.36 m·s⁻¹ (800m
91 pace)¹³. Moreover, significant differences from the non-wetsuit condition in the stroke phases were
92 found^{13,20}. A significant decrease of pull phase percentage (-10.98%) was found at 1.36 m·s⁻¹ (800m
93 pace), while an increase of entry and catch phase (+9.81%) was reported at 1.61 m·s⁻¹ (100m
94 pace)¹³. During a maximal 1500m, an increase of catch phase percentage (+4.9%) and a decrease of
95 propulsive phase time (-10.71% and -11.67%) and percentage (-6% and -5.17%) were found in the
96 first and last 100m, while a decrease of catch phase time (-3.08%) was found only in the last
97 100m²⁰. In addition, the deepest point of wrist trajectory was found to be deeper in underwater

98 phase during a 1500m swim with wetsuit as compared to a swimsuit (+12.5 and +9.84% in the first
99 and last 100m, respectively)²⁰.
100 However, it has to be pointed out that the majority of the studies thus far have tested subjects over a
101 fixed distance or time^{1,7,22–24,9,11,14–17,20,21}, when measuring the effects of wearing a wetsuit.
102 consequently be artefactual *i.e.* attributable to the higher speeds that were reached by the subjects
103 Therefore, all the reported changes in technical parameters that were reported by them may
104 whilst wearing a wetsuit as compared to the non-wetsuit condition. It is easier to determine the
105 changes in stroke related parameters that occur with wetsuit use if only the studies that have used
106 pre-set speeds for both the wetsuit and non-wetsuit conditions are considered. At lower intensities
107 (<80%vVO_{2max}, between 0.67 and 0.94 m·s⁻¹), only increases in SR have been reported¹⁹ with
108 wetsuit use. At higher intensities (*i.e.* 50m and 100m pace, corresponding to 1.72 and 1.61 m·s⁻¹)
109 increases in SL and consequently SI, but not in SR, were reported¹³. Moreover, no changes were
110 reported at intermediate intensities (*i.e.* 800m pace, 1.36 m·s⁻¹) in both SR and SL¹³. The changes in
111 stroke are also supported by the higher deltoids muscle activity that has been found in a simulated
112 swimming test while wearing a wetsuit²⁵. Future studies on the current topic are needed to elucidate
113 the stroke variable changes at different pre-set speed intensities.
114

115 *Leg technique*

116 Swimming with wetsuit showed no effects on leg technique¹³, but a lower number of
117 kicks per stroke cycle was found in active kickers subjects (*i.e.* with a 6 beat kick per cycle
118 stroke)²¹. Whilst the change in leg technique has not been confirmed experimentally^{13,21}, some
119 athletes have self-reported a perceived decrease in leg use whilst swimming with wetsuit over the
120 control condition^{11,24}. Remarkably, a decrease in leg use is crucial on overall performance in both
121 triathlon, where athletes have to cycle and run after the swim, and in open-water swimmers,
122 because despite swimming for 10km, the best athletes significantly increase their speed within the
123 last few hundred meters of the race to sprint for a medal²⁶. New overall indexes of coordination
124 during swimming, such as the index of synchronization and the index of inter-limb coordination²⁷
125 were recently proposed. But, to the best of our knowledge, no study to date has investigated the
126 effects of using a wetsuit on overall coordination by such indices.
127

128 *Physiological data*

129 Wearing a wetsuit indirectly affects the physiological (performance-related) variables of the
130 athletes. Although VO_{2max} itself is unchanged¹⁹, the speed at which both VO_{2max} (vVO_{2max}) (+5-
131 6%)^{19,22} and lactate threshold (v_{LT}) (+3.4%)¹⁷ are reached become higher with wetsuit. Indeed,
132 the studies that have tested the effect of wetsuit use at pre-set swimming speeds noted a decrease in
133 C_{sw}^{17,19,22} and VO₂ at submaximal intensities^{4,19}. These findings may be attributed to the enhanced
134 buoyancy, especially at lower speeds, and the increase of propelling proficiency
135 (previously reported) as a consequence of wetsuit use¹⁹. However, no difference in VO₂ has been
136 reported at higher intensities (≥80% of vVO_{2max}), probably because this speed might be sufficient to
137 generate a hydrostatic lift force to minimize the effects of the added buoyancy of a wetsuit¹⁹.
138 Indeed, the lower limbs are already maintained in a horizontal position at a swim speed that is
139 above 1.4 m·s⁻¹^{16,28}. Blood lactate concentrations ([La⁻])^{1,7,19} and heart rate (HR)^{1,7,14,21} responses to
140 swimming with a wetsuit have been shown not to change, especially during pre-set speed tests.
141

142 *Perceptual response*

143 The perceptual responses of swimming whilst wearing a wetsuit are also of interest. Rating of
144 perceived exertion (RPE) values have been shown to be unaffected by swimming with a wetsuit,
145 both during pre-set speed^{1,4}, distance^{14,21,22} and time⁷ tests. Only at a pre-set speed of 1.31 m·s⁻¹, a
146 significant decrease in RPE was reported when wearing a wetsuit, but not at lower speeds⁴. Some
147 studies evaluated the perceptual response or the comfort/discomfort of swimming whilst wearing a
148 wetsuit by questionnaires^{9,11,24} or scales^{11,14,21}. Although athletes perceived themselves to be

149 swimming faster with a wetsuit^{9,11,24}, they also reported that swimming wearing a wetsuit is less
150 comfortable than swimming without one^{14,21}.

151

152 **Performance**

153 As results of drag, buoyancy and propelling proficiency changes, swimming with
154 wetsuit, whether over a pre-set distance or for a pre-set time, elicited a significant (-3.23 to -11%)
155 decrease in time to complete the distance and an increase (between +2.34 and +9.2%) in mean
156 swimming speed^{1,7,23,24,9,11,14,16,17,20-22} over the control condition. However, the exact extent to
157 which performance is improved by wetsuit use still requires investigation. It is important to
158 highlight that the studies that are covered by this review were published over a large range of years
159 (from 1986 to 2020). The discrepancies in the results of the various studies may, consequently, be
160 partially due to technological improvements in wetsuit design. As reported by Millet and Vleck²⁹,
161 the benefit of wetsuit use to swim times in ITU World Cup competitions appeared to progressively
162 increase over the period 1997-2008, for both genders. The benefit of wearing a wetsuit in
163 competition may (still) be increasing, probably due to technological improvement in wetsuit design.
164 Also, the extent to which wearing a wetsuit may prove beneficial (*i.e.* propelling proficiency,
165 physiological data and perceptual response) are affected by the individual characteristics of the
166 athlete, including swimming capacity, and to the wetsuit model that is utilised^{8,13,14}.

167

168 **Swimming ability**

169 Higher performance improvements were found in triathletes, who are more familiar with wetsuit
170 use, than have been reported for pool swimmers^{14,16} (Table 3). Changes in SR^{14,16}, SL¹⁴, passive
171 drag¹⁶ and Csw¹⁶ were found in triathletes, but not in pool-swimmers,
172 although the same increase in the hydrodynamic lift was reported when wearing a wetsuit^{14,16}. The
173 inconsistent results in the literature about the effect of wetsuit on leg technique that
174 were referred to earlier may be explained by the ability to swim with a wetsuit. In fact, pool
175 swimmers, unaccustomed to wearing a wetsuit, showed lower beat kick per stroke cycle²¹, while no
176 change in leg coordination was reported in triathletes¹³. In addition, the perceived comfort of
177 swimming wearing a wetsuit was worse in pool-swimmers, compared to triathletes¹⁴.
178 Although it has been suggested that leaner subjects and/or poorer swimmers (that correspond to the
179 triathletes profile compared to pool swimmers) can benefit greatly from wearing a wetsuit¹⁶, higher
180 performance improvements have been observed in faster triathletes than in slower ones²⁴.
181 Unfortunately, it is not clear whether the difference in the reported effects of wetsuit use
182 are more related to the ability of an athlete to swim with a wetsuit or individual
183 characteristics, as swimming skill and body fat level. Indeed, when comparing
184 triathletes and pool swimmers, the subjects differed both in anthropometrical
185 characteristics (*i.e.* weight, body mass, both influencing hydrostatic lift) and familiarization with the
186 wetsuit^{14,16}. However, although in all the reported studies triathletes were described as being
187 familiar with wetsuit use, no information about how this familiarization was evaluated has been
188 reported^{1,4,19,20,22,6,9,11,13-17}. Indeed, the use of a wetsuit has effects on muscle activation²⁵ and
189 technique^{1,7,13,14,16,19,20,22} during swimming. It is reasonable to hypothesize that an adequate level of
190 familiarization is needed to adapt an athlete to this new motor skill. However, to date, there are
191 no clear indications of when it may be appropriate to consider an athlete to be “familiar” with
192 wetsuit use. We should be cautious in the interpretation of the results of studies that, in the attempt
193 to evaluate the effects of wetsuit use, recruited athletes of different disciplines and/or swimming
194 ability (as triathletes and pool swimmers)^{1,7,15,17}.

195

196 Table 3

197

198 **Wetsuit models**

199 In order to adapt the wetsuit to individual characteristics, its thickness usually differs between the
200 sections that correspond to different parts of the athlete's body. As ruled, the thickness of the
201 neoprene cannot exceed 5mm, in any part of the wetsuit², in triathlon competitions, while it cannot
202 be thinner than 3mm³ in open-water swimming competitions. In general, a wetsuit has to cover the
203 torso, back, shoulders and knees. Depending on the wetsuit model^{2,3} it may also cover other parts of
204 the body, except face, hands, and feet. In fact, three different wetsuit models are available and
205 utilized: 1) full-sleeve: covering the whole body except for the face, hands and feet; 2) long-
206 sleeveless: covering the whole body except for the face, upper arms and feet and; 3) short-
207 sleeveless: covering the entire body apart from the face, upper arms and calves.
208 Better performance enhancements were reported when the athletes were wearing a long-sleeveless
209 as compared to a full wetsuit^{14,21} (Table 4). As a practical recommendation, it has been suggested
210 that subjects with a weak hydrostatic lift ($HL < 10N$) and/or a low swimming speed ($< 1.31 \text{ m}\cdot\text{s}^{-1}$) use
211 a full wetsuit instead of a long-sleeveless model^{14,16}. However, athletes reported higher rates of
212 discomfort when they were wearing a full wetsuit than when they wore a long-sleeveless ones^{14,21}.
213 Anecdotally, a more important change in swim technique is attributed to the use of a full wetsuit. A
214 full wetsuit could limit the movements during the swim but, at the same time, it may increase the
215 positive effects of buoyancy and passive drag. Indeed, the HL increase was reported to be higher
216 wearing a full wetsuit (+148%) as compared to a long sleeveless (+128%)¹⁴. Moreover,
217 physiological values such as VO_2 and V_E decreased more with a full-, as compared to a long- and
218 short-sleeveless wetsuit at different pre-set speeds⁴. While the values of RER, HR and RPE did not
219 change between wetsuit models^{4,14,21}. No difference in SR and SL was found between wetsuit
220 models^{14,21}, while a lower number of kick beats per stroke was shown in active kicker pool
221 swimmers wearing a full wetsuit, as compared to the long-sleeveless wetsuit condition²¹. To our
222 knowledge, no study comparing wetsuit models has investigated other stroke variables (*i.e.* IdC,
223 phases, etc) or overall indexes of coordination. The information about the short-sleeveless wetsuits
224 appears to be scarce. We are unaware of any study evaluating the change in performance time or
225 mean swim speed when a short sleeveless wetsuit is worn. More studies are needed to define the
226 effects on swimming when wearing a short-sleeveless wetsuit and to compare the results with those
227 that are available regarding the other wetsuit models.

228

229 Table 4

230

231 ***Environmental test settings***

232 In general, the reported improvement in performance appears to be dependent on several factors.
233 However, the results of each study are not necessarily generalizable. Considering that the reported
234 studies evaluated only limited distances (*i.e.* 25²², 30¹⁷, 400^{1,14,16,22,23}, 800²¹, 1000²⁴ or
235 1500m^{11,17,20,23}) and in a warm ($> 20^\circ\text{C}$ ^{1,4,22,23,7,11,14-17,20,21}) pool^{1,7,21-24,9,11,13-17,20} or flume^{1,4,6,19,22}
236 environment, it is unknown whether the reported performance benefits of wearing a wetsuit are
237 related to the distance that athletes will have to swim (*i.e.* from 750m to 3800m in triathlon and
238 from 5 to 25 km in open water races). Indeed, several additional factors, as the different buoyancy,
239 the movement of waves and differences in the effective distance that has been covered³⁰, have to be
240 taken into account when evaluating swimming within an open-water environment, as compared to
241 the swimming flume and pool. In fact, the athlete's experience in a specific water environment
242 plays a significant role in his/her performance³¹. The speeds (ranging between 0.67 and 1.72 $\text{m}\cdot\text{s}^{-1}$)
243 which athletes were tested within the various wetsuit studies are comparable to the mean swimming
244 speed of international-level triathletes (1.36-1.27 $\text{m}\cdot\text{s}^{-1}$ during 1500m³², with single elite athletes
245 who also reach 1.41 $\text{m}\cdot\text{s}^{-1}$, or 1.31-1.20 $\text{m}\cdot\text{s}^{-1}$ -during a 3.8Km³³) and open-water swimmers (> 1.30
246 $\text{m}\cdot\text{s}^{-1}$ for all distances²⁶). It has to be pointed out that all the athletes were tested only over a few
247 meters ($\sim 25\text{m}$)^{13,15-17,22} or a short time (5min)^{4,19} at the selected race-pace speeds. Moreover, most
248 of the studies focused on triathletes^{1,6,9,11,13,19,20,22}, pool swimmers^{4,21,23,24} or both^{7,14-17}, and only one
249 study, up to date, included open water swimmers¹.

250
251 **PRACTICAL APPLICATIONS AND FUTURE PERSPECTIVES**

252 Although the use of a wetsuit has been demonstrated to elicit an important improvement in
253 swimming performance, more studies are needed to understand these reasons and eventually of any
254 possible negative effects. Prior familiarization with wetsuits seems to be an important issue, but it
255 may not be the only key influencing factor of the extent of performance enhancement that is
256 obtained. Since muscle activity has been found to differ between the non-wetsuit and wetsuit-
257 conditions²⁵, and athletes have generally reported higher levels of discomfort while wearing a
258 wetsuit^{14,21}, it seems necessary to test the effect of wetsuit use over longer distances. Moreover, a
259 clear definition of what constitutes an athlete who is “familiar” or “unfamiliar” with wetsuit use is
260 lacking in the literature.

261 The swimming ability of the athlete and the wetsuit model may also play an important role²⁹. The
262 literature results^{22,24} are not unanimous in indicating whether more or less skilled athletes benefit
263 from wetsuit use, but it has to be pointed out that none of the tested athletes can be considered elite
264 or accustomed to wetsuit use. We might hypothesize that elite athletes will benefit less percentage-
265 wise than what has been reported by this review. However, to our knowledge, no comparative data
266 for elite vs. non elite athletes, in wetsuit vs. non-wetsuit conditions, exist. As the introduction of
267 wetsuit use in official open water races is only recent (2017) it is necessary to understand how the
268 swimming technique of open water swimmers, who as a group are unaccustomed to racing with a
269 wetsuit, might change with increasing distance and with increasing levels of fatigue throughout the
270 race. Moreover, the majority of studies thus far have tested wetsuit use at water temperatures that
271 are above the range that the International Triathlon or Swimming Federation consider wetsuit use to
272 be mandatory. Therefore, more studies that simulate true competition settings (in terms of water
273 temperature, open water, and longer distances) are needed, as studies that compare different levels
274 of athletes.

275
276 **CONCLUSIONS**

277 Swimming wearing a wetsuit has been shown to elicit significant improvements in performance, but
278 the amplitude of this improvement remains questionable. This enhancement in swimming
279 performance is attributable merely to improvements in propulsion proficiency, buoyancy and
280 reduction in drag. However, the extent to which athletes are familiar with the use of a wetsuit, their
281 swimming ability, and the model of wetsuit that is involved may play important roles in this
282 improvement.

283
284 Detailed data are provided in the Supplementary online material (*i.e.* summary of the different
285 methodologies in the wetsuit studies, effects of wetsuit use in biomechanical and physiological
286 factors).

287
288 **Acknowledgements**

289 VV acknowledges the support of the Fundação para a Ciência e Tecnologia – as expressed by
290 Grants SFRH/BPD/104394/2014 and UIDB/00447/2020 to CIPER - Centro Interdisciplinar para o
291 Estudo da Performance Humana (unit 447).

292
293 **References**

- 294 1. Gay A, Lopez-Contreras G, Fernandes RJ, Arellano R. Is swimmers performance influenced
295 by wetsuit use? *Int J Sports Physiol Perform.* 2020;15(1):46-51. doi:10.1123/ijsp.2018-
296 0891
- 297 2. International Triathlon Union. ITU Competition Rules. 2018;(November).
298 https://www.triathlon.org/uploads/docs/itusport_competition-rules_2019.pdf.
- 299 3. Fédération Internationale de Natation. FINA Requirements for Swimwear Approval. 2017.
300 <http://www.fina.org/sites/default/files/frsa.pdf>.

- 301 4. Trappe TA, Pease DL, Trappe SW, Troup JP, Burke ER. Physiological responses to
302 swimming while wearing a wet suit. *Int J Sports Med.* 1996;17(2):111-114. doi:10.1055/s-
303 2007-972817
- 304 5. Melau J, Mathiassen M, Stensrud T, Tipton M, Hisdal J. Core Temperature in Triathletes
305 during Swimming with Wetsuit in 10 °C Cold Water. *Sports.* 2019;7(6):130.
306 doi:10.3390/sports7060130
- 307 6. Saycell J, Lomax M, Massey H, Tipton M. Scientific rationale for changing lower water
308 temperature limits for triathlon racing to 12°C with wetsuits and 16°C without wetsuits. *Br J*
309 *Sports Med.* 2018;52(11):702-708. doi:10.1136/bjsports-2017-098914
- 310 7. Trappe TA, Starling RD, Jozsi AC, et al. Thermal responses to swimming in three water
311 temperatures: influence of a wetsuit. *Med Sci Sports Exerc.* 1995;27(7):1014-1021.
312 doi:10.1249/00005768-199507000-00010
- 313 8. Chatard JC, Millet G. Effects of Wetsuit Use in Swimming Events: Practical
314 Recommendations. *Sport Med.* 1996;22(2):70-75. doi:10.2165/00007256-199622020-00002
- 315 9. Parsons L, Day SJ. Do wet suits affect swimming speed? *Br J Sports Med.* 1986;20(3):129-
316 131. doi:10.1136/bjism.20.3.129
- 317 10. Naebe M, Robins N, Wang X, Collins P. Assessment of performance properties of wetsuits.
318 *Proc Inst Mech Eng Part P J Sport Eng Technol.* 2013;227(4):255-264.
319 doi:10.1177/1754337113481967
- 320 11. Lowdon BJ, McKenzie D, Ridge BR. Effects of clothing and water temperature on swim
321 performance. *Aust J Sci Med Sport.* 1992;24(2):33-38.
- 322 12. Hall J, Lomax M, Massey HC, Tipton MJ. Thermal response of triathletes to 14°C swim with
323 and without wetsuits. *Extrem Physiol Med.* 2015;4(S1):1-2. doi:10.1186/2046-7648-4-s1-a49
- 324 13. Hue O, Benavente H, Chollet D. The effect of wet suit use by triathletes: An analysis of the
325 different phases of arm movement. *J Sports Sci.* 2003;21(12):1025-1030.
326 doi:10.1080/0264041031000140419
- 327 14. Perrier D, Monteil M. Wetsuit and performance: influence of technical abilities. *J Hum Mov*
328 *Stud.* 2001;41(3):191-207.
- 329 15. Toussaint HM, Bruinik L, Coster R, et al. Effect of a triathlon wetsuit on drag during
330 swimming. *Med Sci Sports Exerc.* 1989;21(3):325-328. doi:0195-9131/89/2103-0325\$2.00/0
- 331 16. Chatard JC, Senegas X, Selles M, Dreanot P, Geysant A. Wetsuit effect: a comparison
332 between competitive swimmers and triathletes. *Med Sci Sports Exerc.* 1995;27(4):580-586.
- 333 17. De Lucas RD, Balikian P, Neiva CM, Greco CC, Denadai BS. The effects of wet suits on
334 physiological and biomechanical indices during swimming. *J Sci Med Sport.* 2000;3(1):1-8.
335 doi:10.1016/S1440-2440(00)80042-0
- 336 18. Toussaint HM, Roos PE, Kolmogorov S. The determination of drag in front crawl
337 swimming. *J Biomech.* 2004;37(11):1655-1663. doi:10.1016/j.jbiomech.2004.02.020
- 338 19. Tomikawa M, Shimoyama Y, Nomura T. Factors related to the advantageous effects of
339 wearing a wetsuit during swimming at different submaximal velocity in triathletes. *J Sci Med*
340 *Sport.* 2008;11(4):417-423. doi:10.1016/j.jsams.2007.02.005
- 341 20. Perrier D, Monteil K. Triathlon Wet Suit and Technical Parameters at the Start and End of a
342 1500-m Swim. *J Appl Biomech.* 2004;20(1):3-13. doi:10.1123/jab.20.1.3
- 343 21. Nicolaou KD, Kozusko JM, Bishop PA. The effect of wetsuit on swim performance. *J Swim*
344 *Res.* 2001;15:20-26.
- 345 22. Tomikawa M, Nomura T. Relationships between swim performance, maximal oxygen uptake
346 and peak power output when wearing a wetsuit. *J Sci Med Sport.* 2009;12(2):317-322.
347 doi:10.1016/j.jsams.2007.10.009
- 348 23. Cordain L, Kopriva MS R. Wetsuits, body and Swimming Performance. *Br J Sports Med.*
349 1991;25(1):31-33. doi:10.1136/bjism.25.1.31
- 350 24. Townsend MAR, Murray M. Effects of wetsuits on swimming times under controlled
351 seawater conditions. *New Zel J Heal Phys Educ Recreat.* 1991;24(3):24-26.

- 352 25. Agnelli C, Mercer JA. Muscle Activity during Dryland Swimming while Wearing a
353 Triathlon Wetsuit. *Int J Kinesiol Sport Sci.* 2018;6(1):7-11. doi:10.7575/aiac.ijkss.v.6n.1p.7
- 354 26. Baldassarre R, Bonifazi M, Piacentini MF. Pacing profile in the main international open-
355 water swimming competitions. *Eur J Sport Sci.* 2019;19(4):422-431.
356 doi:10.1080/17461391.2018.1527946
- 357 27. Mezêncio B, Pinho JP, Huebner R, Vilas-Boas JP, Amadio AC, Serrão JC. Overall indexes
358 of coordination in front crawl swimming. *J Sports Sci.* 2020;38(8):910-917.
359 doi:10.1080/02640414.2020.1737349
- 360 28. Zamparo P, Gatta G, Pendergast D, Capelli C. Active and passive drag: The role of trunk
361 incline. *Eur J Appl Physiol.* 2009;106(2):195-205. doi:10.1007/s00421-009-1007-8
- 362 29. Millet GP, Vleck VE. Triathlon specificity (chapter 25). In: *World Book of Swimming: From*
363 *Science to Performance.* ; 2010:1-15.
- 364 30. Shaw G, Koivisto A, Gerrard D, Burke LM. Nutrition considerations for open-water
365 swimming. *Int J Sport Nutr Exerc Metab.* 2014;24(4):373-381. doi:10.1123/ijsnem.2014-
366 0018
- 367 31. Tipton M, Reilly T, Rees A, Spray G, Golden F. Swimming Performance in Surf: The
368 Influence of Experience. *Int J Sports Med.* 2008;29(11):895-898. doi:10.1055/s-2008-
369 1038510
- 370 32. Cejuela R, Cortell-Tormo JM, Chinchilla-Mira JJ, Pérez-Turpin JA, Villa JG. Gender
371 differences in elite Olympic distance triathlon performances. *J Hum Sport Exerc.*
372 2012;7(S2):434-445. doi:10.4100/jhse.2012.72.09
- 373 33. Lepers R. Sex difference in triathlon performance. *Front Physiol.* 2019;Jul 24(10:973).
374 doi:10.3389/fphys.2019.00973
375

Swim Length	Forbidden	Mandatory	Event cancelled
Open Water (FINA)	20°C and higher	18°C and lower	Lower than 16.0°C
1501m and longer (WT)	22°C and higher	15.9°C and lower	Lower than 12.0°C
1501m and longer for age group (WT)	24.6°C and higher	15.9°C and lower	Lower than 12.0°C
Up to 1500m (WT)	20°C and higher	15.9°C and lower	Lower than 12.0°C
Up to 1500m for age group (WT)	22°C and higher	15.9°C and lower	Lower than 12.0°C

Table 1 – Temperature rules for wetsuit use regulated by International Triathlon Union (now World Triathlon; WT)² and Fédération Internationale de Natation (FINA)³.

Author (year)	Environment (location, pool length, temperature)	Evaluation of performance	Subjects	Age (years)	Level	Wetsuit (model, thickness)
Parsons et al. (1986) ⁹	Outdoor Pool 66y ~ 60.35m 18°C	30 min.	Tri	20-50+	From Novice to Elite	LS: No details
Toussaint et al. (1989) ¹⁵	Pool - 26°C	10x23m at constant velocity between 1.0 and 1.8 m·s ⁻¹	Tri+Swi	Tri: 27-35 Swi: 22-29	-	LS: No details
Cordain and Kopriva (1991) ²³	Pool 25y ~ 22.86m 26-28°C	400m 1500m	Swi	19.09±0.9	-	LS: 3mm
Towsend and Murray (1991) ²⁴	Outdoor Pool 60m Unheated seawater	1000m maximal	Swi	Under 30-over 40	Moderately trained	No details
Lowdon et al. (1992) ¹¹	Outdoor/Indoor Pool 50/25m 17, 21.3, 29.5 °C	1500m maximal	Tri	28.6 ±6.37	From International to Club	LS: 2mm
Chatard et al. (1995) ¹⁶	Pool 50m 26-26.5°C	Incremental test 13m towed 400m maximal	Tri+Swi	Tri: 18-22 Swi: 18-22	International	F: 5mm trunk, 3mm arms, 3mm legs
Trappe et al. (1995) ⁷	Pool 25y ~ 22.86m 20.08, 22.73, 25.59 °C	30 min at triathlon race pace	Tri+Swi	22.8-58.2	-	LS: 3mm trunk, 4mm legs
Trappe et al. (1996) ⁴	Flume - 26.5°C	0.90 m·s ⁻¹ (=28.9% vVO _{2peak}), 1.05 m·s ⁻¹ (=36.7% vVO _{2peak}), 1.18 m·s ⁻¹ (=45.4% vVO _{2peak}), 1.31 m·s ⁻¹ (=64.5% vVO _{2peak}) (5 min)	Swi	26.3±1.3	Moderately trained	F+LS+SS: 3-4mm
de Lucas et al. (2000) ¹⁷	Pool 25m 25-26°C	Incremental test (3x200m) 30m maximal 1500m maximal	Tri+Swi	Male: 20.7±4.4 Female: 22.0±3.1	Tri: National Swi: Regional	F: 5mm trunk, 3mm arms, 3mm legs

Perrier and Monteil (2001)¹⁴	Pool 25m 26°C	400m maximal	Tri+Swi	Tri: 23±4 Swi: 23±6	Tri: National Swi: Regional	F: 5mm trunk, 3mm arms, 5mm legs LS: 5mm trunk, 5mm legs
Nicolaou et al. (2001)²¹	Pool 50m 27°C	800m	Swi	19.6±1.7	University team	F: 5mm chest/torso, 2- 3mm back, 3mm arms, 3mm legs LS: 5mm chest/torso, 2- 3mm back, 3mm legs
Hue et al. (2003)¹³	Pool 25m -	25m v _{50m} 25m v _{100m} 25m v _{800m}	Tri	23.7±3.1	International and National	F: 5mm trunk, 3mm arms, 3mm legs
Perrier and Monteil (2004)²⁰	Pool 50m 26°C	1500m at triathlon race pace	Tri	24.8±3.7	International and National	F: 5mm trunk, 1.5mm arms, 5mm legs
Tomikawa et al. (2008)¹⁹	Flume - -	Incremental test for VO _{2max} 60%vVO _{2max} (5 min) 80%vVO _{2max} (5 min)	Tri	21.7±2.9	International, National and Inter- collegiate	F: 5mm trunk, 2-3mm arms, 2-3mm legs
Tomikawa and Nomura (2009)²²	Flume (no info) and Pool - 25.7-27.7°C	Incremental test for VO _{2max} 2x25m 400m maximal	Tri	20±1	International and National	F: 5mm trunk, 2-3mm arms, 2-3mm legs
Saycell et al. (2018)⁶	Flume - 10, 12, 14, 16°C	20 min at triathlon Olympic distance race pace	Tri	16-61	Competing at ITU-events	F: No details
Gay et al. (2020)¹	Flume and Pool 25m 27°C	400m maximal	Tri+OWS	Male: 26.3±12.8 Female: 26.69±10.34	-	F: 2.72mm trunk, 2.20mm arms, 2.58mm legs

Table 2 – Summary of wetsuit studies, in order of publication date, with details of the testing environment (*i.e.* location, pool length, water temperature), distance or speed that was tested, type, year and level of subjects that were recruited and thickness of wetsuits that were used. The studies were selected based on: English language full-text and athlete subject recruited. Swi= pool swimmers; Tri= triathletes; OWS= open water swimmers; vVO_{2peak}= speed at VO_{2peak}; vVO_{2max}= speed at VO_{2max}; v_{50/100/800m}= speed at 50/100/800m swimming pace; F=Full model; LS= Long sleeveless model; SS= Short sleeveless model.

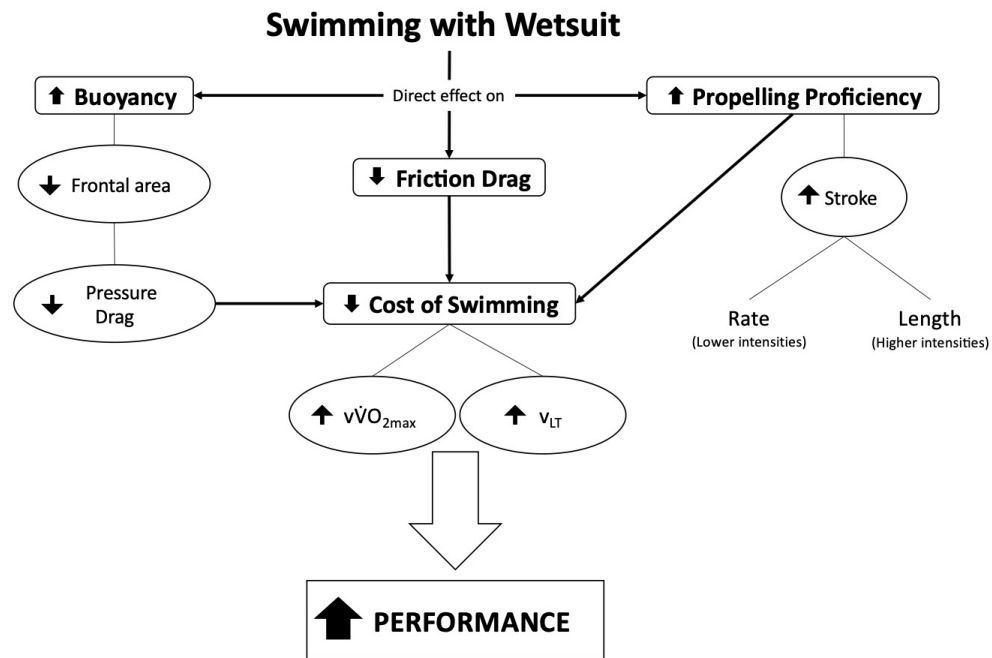


Figure 1 – Effects of wearing a wetsuit on swimming performance. ↑ increase; ↓ decrease; $v\dot{V}O_{2max}$ = speed at VO_{2max} ; v_{LT} = speed at lactate threshold.

470x316mm (72 x 72 DPI)

Performance Level		Time	SL	SR	Drag	HL	RPE	HR	V _{O2}	[La ⁻]	C _{sw}
Same ¹⁴	Tri	--	++	=		+	=	=			
	Swi	-	+	=		+	=	=			
Different ¹⁶	Tri (slower)	-		+	-				=	+	-
	Swi (faster)	=		=	=				-	-	=

Table 3 – Summary of the effects of wearing a wetsuit on triathletes and pool swimmers. Performance level indicates the direct comparison between triathletes and pool swimmers with the same or a different time performance over a 400m swim. SL=stroke length; SR=stroke rate; HL=hydrodynamic lift; RPE=rating of perceived exertion; V_{O2}=oxygen uptake; [La⁻]=blood lactate concentration; C_{sw}=energy cost of swimming; + increase (number of + describes increase entity); - decrease (number of - describes decrease entity); = no change; Tri=triathletes; Swi=pool swimmers

Model	Time 14,21	SL 14,21	SR 14,21	KI 21	HL 14	RPE 4,14,21	HR 4,14,21	V_{O2} 4	V_E 4	RER 4	Comfort 14,21
Full	-	=	=	++	++	=*	=*	---	---	=	--
Long	--	=	=	+	+	=*	=*	--	--	=	-
Short						=*	=*	-	-	=	

Table 4 – Summary of the effects of full, long-sleeveless and short-sleeveless wetsuit use on swim performance related parameters. SL=stroke length; SR=stroke rate; KI= kick inhibition; HL=hydrodynamic lift; RPE=rating of perceived exertion; HR= heart rate; V_{O2}=oxygen uptake; V_E=minute ventilation; RER=respiratory exchange ratio; Comfort=perceived comfort; / no information; + increase (number of + describes increase entity); - decrease (number of - describes decrease entity); = no change; * RPE and HR were reported lower during constant speed swimming with a wetsuit only at 1.31 m·s⁻¹.

	25-30m	400m	800m	1000-1500m	30 min
Time		[-9.5 to -4.96]% ^{1,14,16,22,23}	-3.57% ²¹	[-10 to -3.23]% ^{11,14,17,20,24}	
Speed	[+4.3 to +4.9]% ^{17,22}	[+5.98 to +6.9]% ^{1,22}	+2.34% ²¹	+3.42% ¹⁷	[+7 to +9.2]% ^{7,9}
SL		[+2.2 to +4.5]% ^{1,14,22}	= ²¹	+3.21/+5.66%* ²⁰	+9.6% ⁷
SR		[0 to +4.96]% ^{1,14,16,22}		+4.85% ²⁰	
SI		+10.53% ¹		+11.11/+14.13%* ²⁰	
IdC				= ²⁰	
Active Drag	= ^{17,22}				
RPE		= ¹	= ²¹		= ⁴
HR		= ^{1,14}	= ²¹		= ⁴
VO₂		= ^{16,22}			= ⁴
[La]		[0 to +15]% ^{1,16,22}			

Supplementary Table 1 – Summary of changes in technical and physiological parameters while wearing a wetsuit at pre-set distance or time. Pre-set variables in light orange and analysed variables in light blue. SL= stroke length; SR= stroke rate; SI= stroke index; IdC= index of coordination; RPE= rating of perceived exertion; VO₂= oxygen uptake; [La]= blood lactate concentrations; Csw= energy cost of swimming; [] range of reported values; + increase; – decrease; = no difference.

*SL and SI were reported during the first and the last 100m of a maximal 1500m

Speed (m·s ⁻¹)	Intensity	Time Distance	SL	SR	SI	IdC	Active Drag	Passive Drag
0.67/0.7	60% vVO _{2max}	5min	= ¹⁹	+4.2% ¹⁹				
0.90/0.94	80% vVO _{2max}	5min	= ¹⁹	+4.4% ¹⁹				
1.1		13/23m					-16.1% ¹⁵	-22% ¹⁶
1.20		13m						-18% ¹⁶
1.25		23m					-14.2% ¹⁵	
1.30		13m						-14% ¹⁶
1.36	v _{800m}	25m	= ¹³	= ¹³	+5.18% ¹³	+21,88% ¹³		
1.40		13m						-11% ¹⁶
1.50		13/23m					-12.1% ¹⁵	-10% ¹⁶
1.60		13m						-9% ¹⁶
1.61	v _{100m}	25m	+3.47% ¹³	= ¹³	+5.21% ¹³	= ¹³		
1.72	v _{50m}	25m	+3.11% ¹³	= ¹³	+5.92% ¹³	= ¹³		

Supplementary Table 2 – Summary of changes in technical parameters while wearing a wetsuit at pre-set speed.

Pre-set variables in light orange and analysed variables in light blue. SL= stroke length; SR= stroke rate; SI= Stroke index; IdC= Index of Coordination; vVO_{2max}= speed at VO_{2max}; v_{50/100/800m}= speed at 50/100/800m swimming pace; + increase; – decrease; = no difference.

Speed (m·s ⁻¹)	Intensity	Time Distance	RPE	HR	RER	VO ₂	VE	vVO _{2max} vLT	[La]	Csw
0.67/0.7	60% vVO _{2max}	5min	= ¹⁹			-9.4% ¹⁹			= ¹⁹	-14.4% ¹⁹
0.9	29% vVO _{2peak}	5min	= ⁴	= ⁴	= ⁴	-32.48% ⁴	-23.73% ⁴			
0.90/0.94	80% vVO _{2max}	5min	= ¹⁹			NV ¹⁹			= ¹⁹	-7.5% ¹⁹
1.05	37% vVO _{2peak}	5min	= ⁴	= ⁴	= ⁴	-36% ⁴	-24.07% ⁴			
1.1		13m								-20% ¹⁶
1.18	45% vVO _{2peak}	5min	= ⁴	= ⁴	= ⁴	-32.97% ⁴	-24.2% ⁴			
1.20		13m								-14% ¹⁶
1.30		13m								-7% ¹⁶
1.31	65% vVO _{2peak}	5min	-11.59% ⁴	-11.19% ⁴	= ⁴	-31.18% ⁴	-23.48% ⁴			
Incremental test						= ¹⁹		[+5.2 +6] vVO _{2max} ^{19,22} +3.4vLT ¹⁷	= ¹⁹	

Supplementary Table 3 – Summary of changes in physiological parameters whilst wearing a wetsuit at pre-set speed.

Pre-set variables in light orange and analysed variables in light blue. RPE= rating of perceived exertion; RER= respiratory exchange ratio; VO₂= oxygen uptake; V_E= minute ventilation; vVO_{2max}= speed at VO_{2max}; vLT= speed at lactate threshold; [La]= blood lactate concentrations; Csw= Energy cost of swimming; [] range of reported values; + increase; – decrease; = no difference.