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

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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*

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

Screening process and Inclusion criteria

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

Table 2

RESULTS

Figure 1

Drag

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

Propulsion proficiency

Stroke technique

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

phase during a 1500m swim with wetsuit as compared to a swimsuit (+12.5 and +9.84% in the first and last 100m, respectively)²⁰.

However, it has to be pointed out that the majority of the studies thus far have tested subjects over a fixed distance or time^{1,7,22–24,9,11,14–17,20,21}, when measuring the effects of wearing a wetsuit. Consequently, the results may be artefactual *i.e.* attributable to the higher speeds that were reached by the subjects. Therefore, all the reported changes in technical parameters that were reported by them may whilst wearing a wetsuit as compared to the non-wetsuit condition. It is easier to determine the changes in stroke related parameters that occur with wetsuit use if only the studies that have used pre-set speeds for both the wetsuit and non-wetsuit conditions are considered. At lower intensities (<80% $v\dot{V}O_{2max}$, between 0.67 and 0.94 $m\cdot s^{-1}$), only increases in SR have been reported¹⁹ with wetsuit use. At higher intensities (*i.e.* 50m and 100m pace, corresponding to 1.72 and 1.61 $m\cdot s^{-1}$) increases in SL and consequently SI, but not in SR, were reported¹³. Moreover, no changes were reported at intermediate intensities (*i.e.* 800m pace, 1.36 $m\cdot s^{-1}$) in both SR and SL¹³. The changes in stroke are also supported by the higher deltoids muscle activity that has been found in a simulated swimming test while wearing a wetsuit²⁵. Future studies on the current topic are needed to elucidate the stroke variable changes at different pre-set speed intensities.

Leg technique

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

Physiological data

Wearing a wetsuit indirectly affects the physiological (performance-related) variables of the athletes. Although $\dot{V}O_{2max}$ itself is unchanged¹⁹, the speed at which both $\dot{V}O_{2max}$ ($v\dot{V}O_{2max}$) (+5–6%)^{19,22} and lactate threshold (v_{LT}) (+3.4%)¹⁷ are reached become higher with wetsuit. Indeed, the studies that have tested the effect of wetsuit use at pre-set swimming speeds noted a decrease in C_{sw} ^{17,19,22} and $\dot{V}O_2$ at submaximal intensities^{4,19}. These findings may be attributed to the enhanced buoyancy, especially at lower speeds, and the increase of propelling proficiency (previously reported) as a consequence of wetsuit use¹⁹. However, no difference in $\dot{V}O_2$ has been reported at higher intensities ($\geq 80\%$ of $v\dot{V}O_{2max}$), probably because this speed might be sufficient to generate a hydrostatic lift force to minimize the effects of the added buoyancy of a wetsuit¹⁹. Indeed, the lower limbs are already maintained in a horizontal position at a swim speed that is above 1.4 $m\cdot s^{-1}$ ^{16,28}. Blood lactate concentrations ($[La^-]$)^{1,7,19} and heart rate (HR)^{1,7,14,21} responses to swimming with a wetsuit have been shown not to change, especially during pre-set speed tests.

Perceptual response

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

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

Performance

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

Swimming ability

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

Table 3

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.

PRACTICAL APPLICATIONS AND FUTURE PERSPECTIVES

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

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

CONCLUSIONS

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

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

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| Swim Lenght | 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.

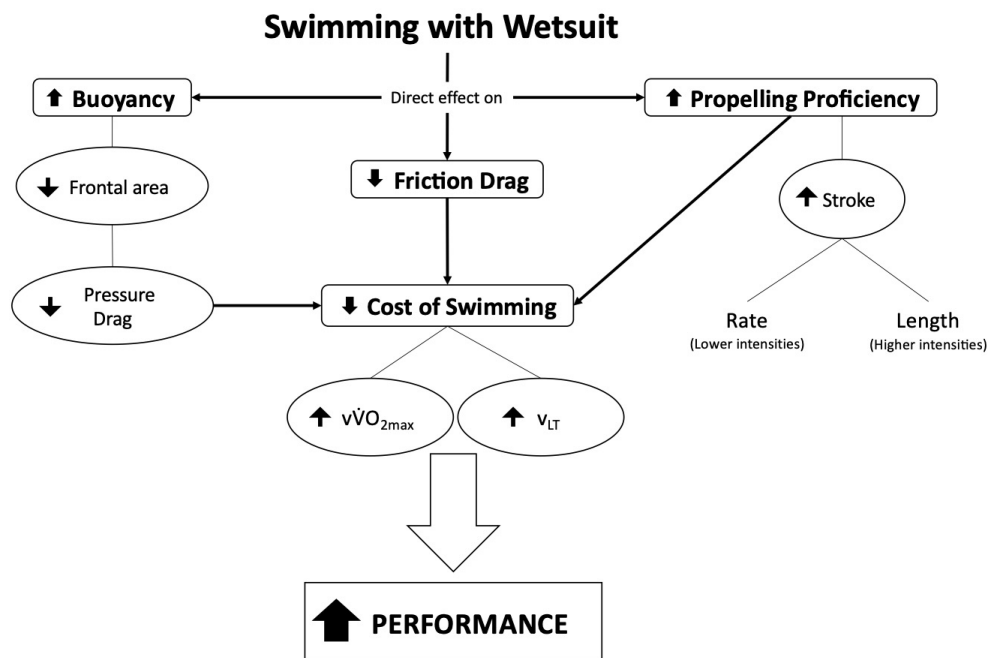


Figure 1 – Effects of wearing a wetsuit on swimming performance. ↑ increase; ↓ decrease; $v\dot{V}O_{2max}$ = speed at $\dot{V}O_{2max}$; v_{LT} = speed at lactate threshold.

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 |
| VO ₂ | | = ^{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] vV _{O2max} ^{19,22} +3.4v _{LT} 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}; v_{LT}= speed at lactate threshold; [La]= blood lactate concentrations; Csw= Energy cost of swimming; [] range of reported values; + increase; – decrease; = no difference.