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Article Title: Is Swimmers Performance Influenced by Wetsuit Use?

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Abstract

Purpose: The aim of the current study was to observe the changes in performance, physiological and general kinematical variables induced by the wetsuit vs swimsuit use in both swimming pool and swimming flume conditions. ***Methods:*** Following a randomized and counterbalanced order, 33 swimmers (26.46±11.72 years old) performed 2x400m maximal front crawl in a 25m swimming pool (with wetsuit and swimsuit) and its mean velocities were used afterwards in two swimming flume trials with both suits. Velocity, blood lactate concentrations ([La-]), heart rate (HR), Borg scale (RPE), stroke rate (SR), stroke length (SL), stroke index (SI) and propelling efficiency (η_p) were evaluated. ***Results:*** Swimming pool 400m performance was $0.07 m \cdot s^{-1}$ faster when using the wetsuit than swimsuit, evidencing a reduction of ~6% in time performed ($p<0.001$). HR_{max}, $[La-]_{max}$, RPE, SR and η_p were similar when using both swimsuits but SL and SI presented higher values with the wetsuit both in swimming pool and swimming flume. Comparing swimming conditions, HR_{max} and $[La-]_{max}$ were lower, and SL, SI and η_p were higher, while swimming in the flume than in the pool both with wet and swimsuit. ***Conclusions:*** The 6% velocity improvement was the result of an increase of 4% in SL. Swimmers reduced SR and increased SL to benefit from the hydrodynamic reduction of the wetsuit and increase the swimming efficiency. The wetsuit might be utilized during the training seasons to improve the adaptations while swimming.

Keywords: swimming flume, open water, triathlon, propelling efficiency, front crawl.

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Introduction

In triathlon and open water swimming official events it is permitted to compete using a wetsuit depending on water temperature, swimming length and age-group (to prevent hypothermia)[1]. Previous research on wetsuit effect focused on performance improvement due to increased buoyancy, which is closely related to lower hydrodynamic body drag[2]. Moreover, wetsuit use reduces hydrodynamic resistance, raising the gliding length and decreasing the energy cost in inefficient swimmers with low buoyancy[3]. In fact, it seems that when wearing a wetsuit there is a reduction in body drag, improving the 400 and 1500 m, and the 30 min, front crawl performances[4-6]. This is especially important as the 400 m distance is well related with the intensities corresponding to the time to exhaustion at the minimum velocity that elicits maximal oxygen consumption $(\dot{V}O_{2max})$[7] and to the critical velocity[8], both frequently used as index of aerobic performance[9].

Open water swimming events with and without wetsuit could be replicated by using a swimming flume. It was observed that the use of a full body wetsuit (covering both upper and lower limbs until the ankles) leads to lower $\dot{V}O_2$ and heart rate (HR) values comparing to long wetsuit (covering trunk and lower limbs until the ankles) and to short wetsuit (covering trunk and lower limbs until the knees)[10], eventually implying lower energy expenditure due to the modified physiological variables ($\dot{V}O_2$ and HR). The wetsuit use also leaded to biomechanical changes in swimming pool, particularly an increase of the stroke rate (SR) and the stroke length (SL) in a 1500 m front crawl time-trial[11]. However, none of the previously referred studies analyzed propelling efficiency (η_p, the ratio of the useful power – the used to overcome drag – to the total power output), one of the major determinants of swimming energy cost[12].

When swimming in a flume, a specific pace is maintained constant during the entire effort, in contrast with what happens in a swimming pool, where swimmers might change speed due to a number of constraints (as fatigue [13]). As a result, changes in the swimming technique

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are produced while performing in the swimming flume. Furthermore, evaluating swimmers technique is easier in the swimming flume than in the swimming pool particularly because in this latter swimmers are propelling themselves along the pool[13,14]. Therefore, an accurate measurement of the wetsuit effect in both swimming conditions might be relevant to increase the efficiency of triathletes and open water swimmers training process.

In the current study, it were analyzed the changes in performance, physiologic and general kinematic variables when using a wetsuit, both in swimming pool and swimming flume conditions. It was hypothesized that using a wetsuit will enhance the 400 m front crawl performance, reduce physiological responses and increase swimming efficiency. Complementarily, it is expected lower physiological and higher technical variables values while performing in the swimming flume comparing to the swimming pool, evidencing a more economic effort.

Methods

Participants

Thirty-three triathletes and open water swimmers (13 females and 20 males) voluntarily participated in the current study. Female and male physical characteristics were 26.69 ± 10.34 vs 26.3 ± 12.8 years old, 165.15 ± 6.12 vs 175.86 ± 7.47 m of height, 58.45 ± 7.55 vs 72.78 ± 9.98 kg of body mass and 15.04 ± 3.22 vs 13.92 ± 2.46% of body fat. Swimmers were engaged in a six to seven weekly training frequency and had 76.15 ± 10.39% for the 100 m front crawl as personal best. Participants or parents (when the subjects were under 18 years old) provided a written informed consent to participate and the Institutional Ethical Review Board approved the study design (which has been performed according to the Code of Ethics of the World Medical Association - Declaration of Helsinki).

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Design

Two 400 m front crawl time-trials, using full body wetsuit (thickness of 2.20 ± 0.61, 2.72 ± 0.94 and 2.58 ± 0.81 mm in upper limbs, trunk and lower limbs, respectively) and swimsuit, were performed in a 25 m swimming pool (with in-water starts and 48 h rest in-between). Afterwards, the corresponding 400 m velocities and time durations were used in two trials (with wetsuit and swimsuit) in a swimming flume. As the swimming flume had a pre-defined velocity range, 400 m trials mean velocities were adjusted to the closest one available so swimmers could perform at the same pace than in the swimming pool. An individual warm-up of 15 min of low to moderate intensity followed by 10 min of passive rest[15] was always performed before testing, and conditions were randomly and counterbalanced performed both between trials and vestment conditions. Participants had previous experience in swimming in the flume and abstained taking caffeinated drinks and practicing exhausting exercise before the experiments.

Methodology

A Panasonic (Full-HD HX-A500, Osaka, Japan) 50 Hz underwater camera recorded the sagittal plan of the swimmers displacement at the center of both pools (12.50 and 2.35 m in the swimming pool and flume, respectively). Pre-calibrated spaces 5 and 1 m long situated in the center of the swimming pool and flume (respectively) were used for video analysis, and reference points were drawn at the participants’ shoulders, hips and wrists for technical variables determination. The swimming flume (Endless Pool Elite Techno Jet Swim 7.5 HP, Aston PA, USA) was 2.4 x 4.7 m of length, with flow velocity being measured at 0.30 cm depth using an FP101 flow probe (Global Water, Gold River, CA[16]). The water temperature was set at 27ºC in both conditions since it is the recommended (and frequently used) water temperature in indoor swimming pools.

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Data Analysis

The 400 m front crawl were recorded with a camera Nikon 1J1 (Nikon Corp., Japan) at 60 frames per second. Timing pads (Alge Timing, Training Pad TP980 Lustenau, Austria) were situated in both sides of the pool. A specific database was developed to measure the video time code and calculate the average velocity at 85 m of each 100 m lap (Filemaker v14.5, California, United States). The time performed in the swimming pool was used to determine the distance which swimmers had to accomplish in the swimming flume (with and without the wetsuit). The mean velocity performed in the swimming pool in both conditions was controlled with the swimming flume monitor.

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HR was recorded using CardioSwim (Freelap, Fleurier, Switzerland) with the maximal HR (HR_{max}) obtained from the average of the last 30 s of the trials. Participants pointed out the Borg rating of perceived exertion scale (RPE)[17] immediately after the efforts and, at the third min of recovery, capillary blood samples (25 μL) for blood lactate concentration ([La-]) analysis were collected from the fingertip (using a Lactate Pro, Arkray, Inc., Kyoto, Japan) to obtain its maximal values ($[La\text{-}]_{max}$)[15].

SR was obtained by considering three upper limb cycles and dividing it for the time taken to complete the three cycles in every 25 m lap corresponding to the 50, 200 and 400 m partials in both swimming pool and flume. SL was obtained from the ratio between the velocity and SR[18]. Stroke index (SI) was calculated by multiplying the swimming velocity by the SL)[19]. η_p was estimated as follows[12] : $\eta_p = [(v \cdot 0.9 / 2\pi \cdot SR \cdot l) \cdot 2/\pi] \cdot 100$, where l is the distance between the shoulder and wrist during the upper limbs insweep.

Statistical Analysis

Using the IBM SPSS Statistics (Version 20, IBM SPSS, Chicago, USA), Kolmogorow-Smirnov confirmed the data normality and homogeneity. A Pair Student's *t*-test was computed to compare 400 m front crawl performance with the wetsuit and swimsuit. ANOVA repeated

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measures was selected to compare the use of a wetsuit and a swimsuit both in swimming pool and flume conditions. Sphericity (homogeneity of variance and covariance) was verified by means of the Mauchley test and, when it was not met the significance of the F-ratios, was adjusted according to the Greenhouse-Geisser procedure. When a significant F value was achieved, Bonferroni post hoc procedures were performed to locate the pairwise differences between the means ($P < 0.05$). The Cohen´s *d* effect was calculated with the following criteria: 0 to 0.19 trivial, 0.2 to 0.59 small, 0.6 to 1.19 moderate, 1.2 to 1.99 large, 2.0 to 3.9 very large and > 4.0 nearly perfect[20].

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Results

Data concerning swimming performance, as well as physiological and technical variables, are presented in Table 1. In average swimmers were faster with the wetsuit than with the swimsuit (in the swimming pool), evidencing a reduction of 20.08 s (~6%) in the time endured at the 400 m front crawl. HR_{max}, $[La-]_{max}$, RPE, SR and η_p were similar between suits conditions (in both pool and flume). SL and SI were higher when wearing the wetsuit (both in the swimming pool and flume). Data displayed in Figure 1 is shown in complementing way to the information of the Table 1.

When comparing swimming conditions, HR_{max}, $[La-]_{max}$, SR and RPE were lower when performing in the flume (for both suits), showing a nearly perfect and very large effect size for the physiological variables, and large and moderate effect size for RPE (with wet and swimsuit, respectively). In contrast, SL, SI and η_p were higher when performing in the flume, showing a nearly perfect effect on η_p. Data is described in Table 1 and the corresponding comparisons displayed in Figure 1.

Discussion

The current study aimed to analyze the differences in the 400 m maximum front crawl performance, and related physiological and general kinematical variables, when using the wetsuit compared to the swimsuit in two typical training conditions (swimming pool and flume). As expected, our swimmers were faster when using the wetsuit, which is consistent with the 5-6% improvement in 400 m[3,5] and 7% in 30 min front crawl[4] previously described. Therefore, the current data corroborate the scientific literature that states that using a wetsuit allows obtaining advantage at aerobic events, probably due to better hydrodynamics[2]. In addition, differences between pools (with and without wetsuit) were also analyzed, being observed for similar velocities a reduction of physiological values and an increment of some technical variables in the swimming flume condition (using both suits).

When comparing physiologically wetsuit and swimsuit, it was not observed differences in HR_{max}, $[La-]_{max}$ and RPE (in both swimming pool and flume), which is contrary to our hypothesis. This could be justified by the fact that the velocity improvement is caused by the hydrodynamic drag reduction[3-6], and not by physiological changes. However, even if the ~10 and 2% $[La-]_{max}$ reduction when using wetsuit in the pool and in the flume (respectively) did not had statistical meaning, it could be relevant for training purposes, for instance justifying the inclusion of higher intensity sets during the training process. Moreover, the obtained $[La-]_{max}$ values are in accordance with the literature for 400 m trials events[3,7,15] but not HR_{max}, whose values were lower with wetsuit and higher with swimsuit comparing with previous results[10,7] (that could be explained by the higher velocities implemented in these studies). In addition, RPE values are similar to those found after swimming 400 m front crawl in a swimming pool with swimsuit[8] supporting the results of the current study. Swimmers RPE is similar with and without wetsuit probably due to their similar energy expenditure requirements between trials as HR_{max} and $[La-]_{max}$ corroborate.

When comparing suits focusing on technical variables, it was observed similar SR values (in swimming pool and in flume), not corroborating the studies where higher values were found with wetsuit[3,21], probably because different 400 m front crawl protocols were

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implemented and different swimmers levels were used. SL presented higher values in the wetsuit condition compared to swimsuit (~4 and ~7%, swimming pool and flume respectively), in accordance with data from the 30 min and 400 m front crawl studies[21,22]. The buoyancy increase imposed by the wetsuit use and the reduction in hydrodynamic drag seems to lead changes in the body position, producing technical adaptations of the swimmers who do not modified their SR. Hence, the swimming efficiency was similar in both situations. On the contrary, SL was 4.3% with wetsuit comparing with swimsuit in the swimming pool, which might be the responsible of the higher velocity reached in the 400 m test with wetsuit.

Swimming efficiency is fundamental to reach high performances (as it is strongly associated with low values of energy cost) and SI is frequently used as an easy to obtain strategy to measure it[19,23,24] . In the current study, SI was higher when using the wetsuit vs swimsuit (in both pools) as expected as it depends on SL, and was similar to data previously reported for the 400 m front crawl[25]. Furthermore, a better efficiency has been observed for the long suits (compared to sleeveless or short suits) due to the enhanced buoyancy and reduction in friction drag[10]. Notwithstanding the observed SI differences between suits, η_p did not differ, probably because swimmers had to modify their technique based on the swimming conditions (swimming pool or swimming flume) and the suit wear. That might be the reason why neither the SR nor η_p were modified. Its values were similar to the literature regardless the methodology used for its assessment, particularly using the Zamparo[12] and MAD-system methods[26,27].

Concerning the second aim of the current study – comparing front crawl swimming at similar velocities in different pools – it was observed lower physiological variables values in the flume (independently of the suit used). This seems to express that swimming at high intensity in a flume is more economic, probably due to the constant pace imposed by the water flow and the absence of turns. These swimming flume constraints induced a better energy

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balance, as observed by the reduction of ~33% of $[La-]_{max}$ and might be truly important for triathletes training process, as they are more engaged in long distance events and have lower vital capacity and skinfold thickness (and, therefore, less buoyancy[28]). The lack of difference in physiological variables migh be also due to the participants do not performed the test maximally in the swimming pool and, as a consequence, niether in the swimming flume. Additionally, swimming against a current in such a reduced place might produce additional propulsion when the water rebounds to the wall of the flume. It avoids swimmers using additional energy to propel themselves or change direction. Therefore, as this work suggested, physiological responses could be reduce due to flume swimming (Table 1). Complementarily, RPE was higher in the swimming pool compared to the flume probably due to the different swimming strategies (free swimming in the pool were they determinate the swimming pace vs imposed paces in the swimming flume), but in contrast with a previous study[17]. This might be related to previous experience when in swimming at the flume (our subjects were used to perform there) and to the characteristics of the different water channels.

Related to technical variables, the increment of the efficiency in the flume can be explained by the possible mechanical constraints induced by the flume, as the narrow displacement of the water impelled and consequent direction of the water around the swimmers body[13]. Additionally, the differences between pools limit the use of the flume to compare data in both conditions. As Figure 1 shows, all the variables are statistically different probably due to the characteristics of the flume of the reduced dimensions and small water impeller.

Practical Applications

Our results add more precision in the adaptation of the training loads when using the wetsuit considering the reduction of 10% of $[La-]_{max}$ with wetsuit and the improvement of the technical efficiency. These results suggested that there are technical adaptations that swimmers should focus on improving the efficiency while swimming with the wetsuit. An improvement

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of a 6% increase in velocity is produced by an increase of 4.3% in the SL with similar values of SR. They might reduce SR and increase the SL in order to benefit of the hydrodynamics characteristic of the wetsuit and improve the efficiency while swimming. A recommendation for trained swimmers, as the simple size used in this study, is using the wetsuit during the training seasons, swimming at different intensities and distances to improve the adaptations while swimming with the wetsuit.

Conclusions

Our data confirmed that wearing a wetsuit leads to a 400 m front crawl performance increment. Additionally, it was observed that physiological variables reached lower values (using both suits) and technical variables (except SR) were higher in the swimming flume. The swimmers improved 6% the velocity with the wetsuit due to the suit itself because they do not change their swim technique as the results show. They increase SL and, as a consequence the velocity was higher. It might be explained by the reduction of hydrodynamic resistance and the changes in the body position, however it was not measured in the present study. More information is needed concerning the influence of wetsuit in swimming performance, particularly by implementing biomechanical and physiological analysis at lower temperatures for a better understanding of the mechanisms underlying open water and triathlon competitions.

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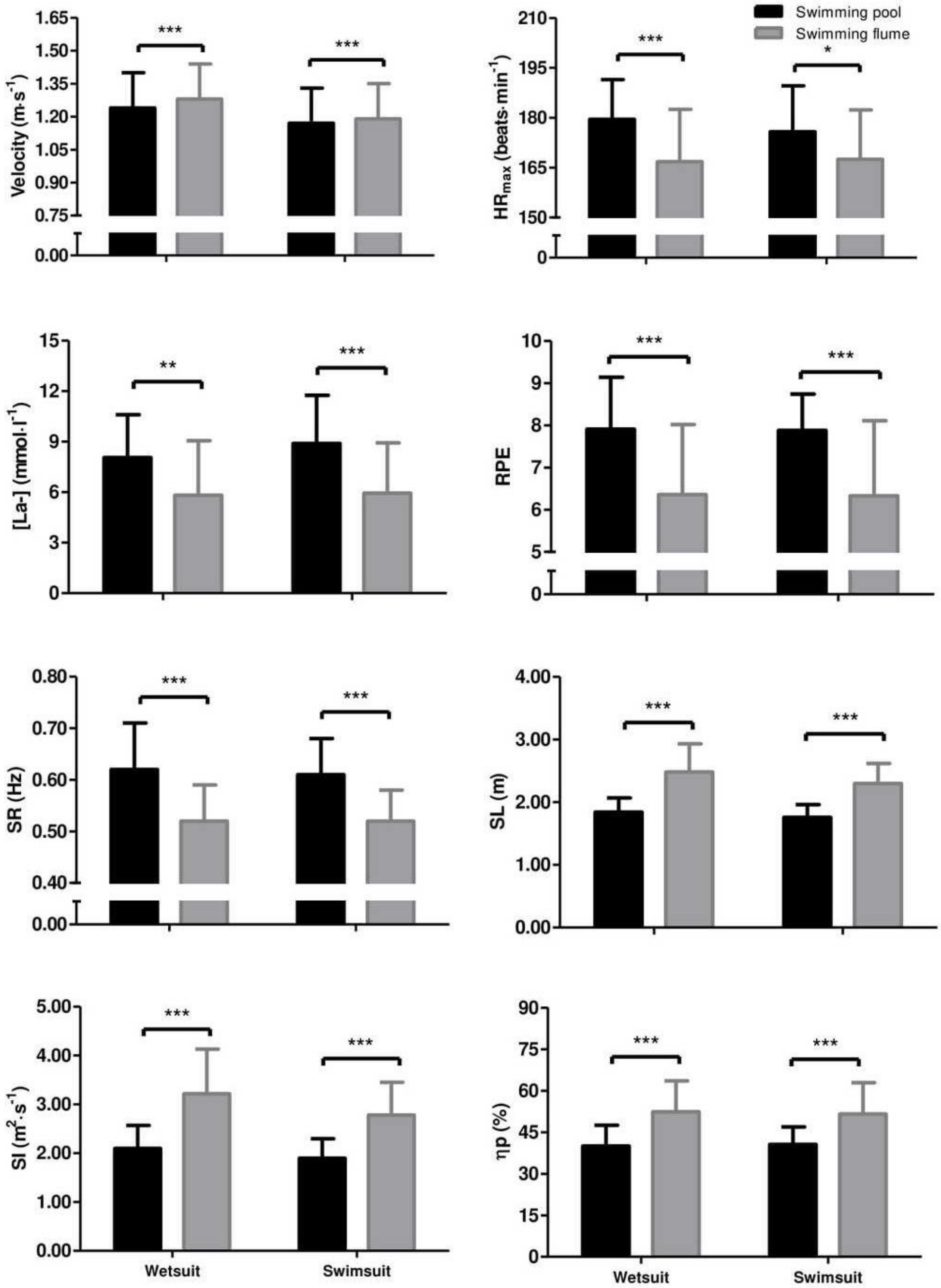

Figure 1. Means and standard deviation of physiological and technical variables plotted with wet and with swimsuit. Black bars represents the swimming pool and grey bars the swimming flume condition. Maximal heart rate (HR_{max}), maximal blood lactate concentrations ($[La^-]_{max}$), Rating of perceived exertion (RPE), stroke rate (SR), stroke length (SL), stroke index (SI) and propelling efficiency (η_p). *, ** and *** mean differences between suits for $p < 0.05$, 0.01 and 0.001.

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Table 1. Values of 400 m maximum front crawl performance and related physiological and technical variables when using wetsuit and swimsuit both in swimming pool and flume conditions.

	SWIMMING POOL				**SWIMMING FLUME**			
Variable	**Wetsuit**	**Swimsuit**	**Difference [95%CI]; %Δ**	**Effect size (d)**	**Wetsuit**	**Swimsuit**	**Difference [95%CI]; %Δ**	**Effect size (d)**
Time endured (s)[1]	328.05 ± 42.85	348.13 ± 46.46***	-20.08 [-24.34, -15.81]; 6.1%	-1.67β	---	---	---	---
Velocity (m·s^{-1})	1.24 ± 0.16	1.17 ± 0.16***	0.07 [0.05, 0.09,]; -5.6%	0.16	1.28 ± 0.16	1.19 ± 0.16**	0.08 [0.06, 0.10]; -7%	0.15
Maximal heart rate (beats·min-^{1})	179.50 ± 11.96	175.80 ± 13.78	3.69, [-3.04, 10.43]; -2.1%	11.93‡	166.76 ± 15.77	167.52 ± 14.80	-0.76 [-5.58, 4.08]; 0.46%	15.77‡
Maximal blood lactate concentrations (mmol·l^{-1})	8.05 ± 2.55	8.89 ± 2.86	-0.84, [-1.81, 0.13]; 10.4%	2.55†	5.82 ± 3.23	5.94 ± 2.99	-0.12 [-1.02, 0.77]; 2.1%	3.34†
Ratio of perceived exertion	7.91 ± 1.23	7.88 ± 0.86	0,03 [-0.59, 0.65]; -0.4%	1.23β	6.36 ± 1.66	6.33 ± 1.78	0.3 [-0.65, 0.70]; -0.5%	16.60‡
Stroke rate (Hz)	0.62 ± 0.09	0.61 ± 0.07	0.01, [-0.01, 0.03]; -1.6%	0.12	0.52 ± 0.07	0.52 ± 0.06	-0.001 [-0.02, 0.02]; 0%	0.07
Stroke length (m)	1.84 ± 0.23	1.76 ± 0.20*	0.07 [0.01, 0.14,]; -4.3%	0.21	2.48 ± 0.45	2.30 ± 0.32***	0.19 [0,09, 0.28]; -7.3%	0.46
Stroke index (m^{2}·s^{-1})	2.10 ± 0.47	1.90 ± 0.40**	0.20 [0.07, 0.34,]; -9.5%	0.48	3.22 ± 0.91	2.78 ± 0.67***	0.45 [0,27, 0.62]; -13.7%	0.92*
Propelling efficiency (%)	40.00 ± 7.51	40.63 ± 6.25	-0.62 [-3.07, 1.83,]; 1.6%	7.40‡	52.41 ± 11.16	51.56 ± 11.30	0.85 [-2.39, 4.08]; -1.6%	11.09‡

[1]This values were similar in swimming pool and flume conditions. *, ** and *** mean differences between suits for $p < 0.05$, 0.01 and 0.001. Cohen´s *d* effect: *moderate, βlarge, †very large and ‡nearly perfect.

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