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Swimming Performance in Elite Triathletes: Comparison Between Open Water and Pool Conditions

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ABSTRACT

This study aimed to compare performance, kinematic, and physiological variables between open water and pool swimming conditions in elite triathletes and to examine the associations between conditions on these variables. Fourteen elite triathletes (10 males and 4 females [23.4 ± 3.8 years]) performed two 1500-m swimming tests in open water and in a 25-m pool. Swimming speed, stroke rate (SR), length (SL) and index (SI), heart rate (HR), blood lactate concentrations [La^-], and end-exercise oxygen uptake ($EE\dot{V}O_2$) were assessed in both conditions. Lower SL and SI and higher SR were obtained in open water compared with pool swimming ($p < 0.05$). Moreover, kinematic variables changed as a function of distance in both conditions ($p < 0.05$). No differences were found in the main physiological variables (HR, [La^-], and $EE\dot{V}O_2$) between conditions. Respiratory exchange ratio presented lower values in open water than in pool conditions ($p < 0.05$), while time constant was higher in open water ($p = 0.032$). The fastest triathletes in open water obtained the best performance in the pool ($r = 0.958$; $p < 0.001$). All kinematic variables, HR and peak [La^-] presented positive associations between conditions ($r > 0.6$; $p < 0.05$). Despite physiological invariance, triathletes and coaches should monitor specific open water training to adapt their swimming technique to the competitive environment.

1 | Introduction

Swimming makes the plunge of triathlon races, where athletes are challenged to subsequently complete cycling and running sections. The established order may potentially impact the performance of the subsequent sections, thus triathletes should manage their effort during a triathlon competition [1]. In fact, the lower energy cost resulting from strategic positioning during the 1500 m swimming may significantly affect the subsequent cycling and running performance [2, 3]. Hence, a good position in the first pack or finish the swimming section close to the leader is essential for triathlon success [4, 5]. However, despite its relevance, the swimming section has been less studied than the cycling and running ones [6], probably as a consequence of the complexity of assessing in the aquatic environment [7].

The swimming section in triathlon competitions takes place in open water conditions, like oceans or lakes, where the environmental circumstances (i.e., waves, tides, or currents) are challenging [8]. However, triathletes' training programs are developed in swimming pool [9], likely to mitigate the constraints of open water environment and for better performance monitoring by

coaches. In this regard, the differences between open water and pool swimming performance have not been examined in triathletes [9] and underexplored in swimmers [10, 11]. Certainly, some research focused on the associations between open water and pool swimming performance, indicating that the fastest open water swimmers also obtained the highest swimming speed in pool events [10]. A similar trend was showed in triathletes, where an incremental pool swimming test may serve as a predictor of the swimming section in a triathlon race (i.e., open water conditions) [12]. However, the open water results were taken from official competitions, which may yield different outcomes when compared to a controlled pool test. Hence, the analysis of open water and pool swimming tests under controlled conditions (i.e., laboratory settings) could provide valuable insights into the differences and associations of performance in both environments.

To understand performance and how athletes deal with the first triathlon section is essential to asses swimming kinematics [7]. For instance, the interaction between performance and stroke variables represent a major point of interest in swimming research, as this interaction allow researchers to identify optimal swimming techniques tailored to individual swimmers, maximizing their speed and efficiency [13]. In that sense, the stroke index (SI) is considered the main predictor in both open water [9] and pool swimming performance in elite triathletes [7], as this parameter essentially reflects how efficiently a swimmer converts their strokes into forward propulsion. On the contrary, the dynamic nature of open water conditions induces kinematic fluctuations and thus affect swimmers' physiological responses differently [8, 11]. In this regard, swimmers' energy expenditure is influenced by the adjustments to face these open water conditions, which may affect oxygen uptake ($\dot{V}O_2$), heart rate (HR), or blood lactate concentrations ([La^-]) [11]. Consequently, the analysis of physiological variables linked to kinematic changes during open water and pool swimming may be of interest to understand the different demands in competitive and usual training environments.

Considering the relevance of swimming as the initial section in a triathlon race and its impact on overall performance, a deeper knowledge about this discipline may lead to more specific training plans. However, to the best of the authors' knowledge, no study has compared triathletes' swimming performance in both environments. Therefore, the aims of the current study were (1) to compare performance, kinematic, and physiological variables between the 1500 m open water and pool swimming conditions and (2) to examine the associations between conditions on these variables. It was hypothesized that open water conditions would deteriorate performance and kinematics compared to pool conditions, leading to greater physiological demands. Moreover, the fastest triathletes in open water swimming would also perform the best times in pool swimming.

2 | Methods

2.1 | Participants

Fourteen world class, international and national [14] triathletes (10 males [23.2 ± 3.7 years, 177.5 ± 6.6 cm of body height and 66.7 ± 7.5 kg of body mass] and 4 females [23.6 ± 4.5 years, 169.8 ± 10.6 cm of body height and 58.3 ± 8.7 kg of body mass]) participated voluntarily in the current study. Two World Championship and World Cup medalists were included among the participants. Triathletes trained in the same team under the supervision of the same certified coach. The protocol was fully explained to the athletes before providing written consent to participate. The study was approved by the Ethics Committee of the University of Granada (project code: 2658/CEIH/2022) and was conducted in accordance with the Declaration of Helsinki.

3 | Design

A counterbalanced crossover study was performed along 4 days during a training camp. Participants were randomly assigned to two groups, performing a 1500 m open water and pool swimming tests in two different days with 48 h of recovery in-between. The sequence order of the swimming conditions was randomly assigned for each group (Figure 1). Both tests were conducted at the same time of the day to avoid circadian variations [15]. The average and maximum total weekly training time (i.e., across all three disciplines) were 15.8 ± 2.7 and 26.8 ± 3.2 h, respectively. This time refers only to actual working time and did not take intraset rest periods into account nor included the resistance training sessions. The training load was calculated for all participants using objective load equivalents (ECOs) model [16], obtaining 1354 ± 184 and 2046 ± 293 ECOs weekly average and maximum, respectively (Figure 1).

3.1 | Open Water and Pool Swimming Conditions

The 1500 m swimming tests were conducted individually with in-water start, preceded by a 1000-m standardized warm-up [17]. Participants used their competition tri-suit (i.e., no wetsuit) and completed the open water and pool swimming tests at race pace, starting with a higher speed in the initial meters [18]. The open water swimming tests were conducted in a lake with 26.8–27.5°C and 29.4–31.2°C water and air temperatures, respectively; 12%–16% relative humidity and 10–14 km/h northwest wind. For the 1500 m open water circuit measurement, a 250 m length rope was placed with small floats every 5 m and two big buoys at each end. The participants completed the 1500 m swimming test with three 500 m rounds (i.e., rope round trip). A total of five 180° turns were performed, leaving the buoys always on the left side. For a better kinematic analysis, each 500-m round was split in two laps of 250 m, analyzing a total of six laps of 250 m. The pool swimming tests were performed in a 25-m indoor pool with 27.9°C, 29.4°C, and 53.3% water and air temperatures and relative humidity, respectively. During the pool tests, the participants were notified at 500, 1000, and 1400 m with a whistle blow. No feedback or encouragement was provided in any of the conditions. During the testing period, triathletes were required to refrain from high-intensity activities.

3.2 | Performance and Kinematic Measurements

The swimming tests were recorded with a Sony FDR-AX53 (Sony Electronics Inc) at 50 Hz sampling rate. In open water

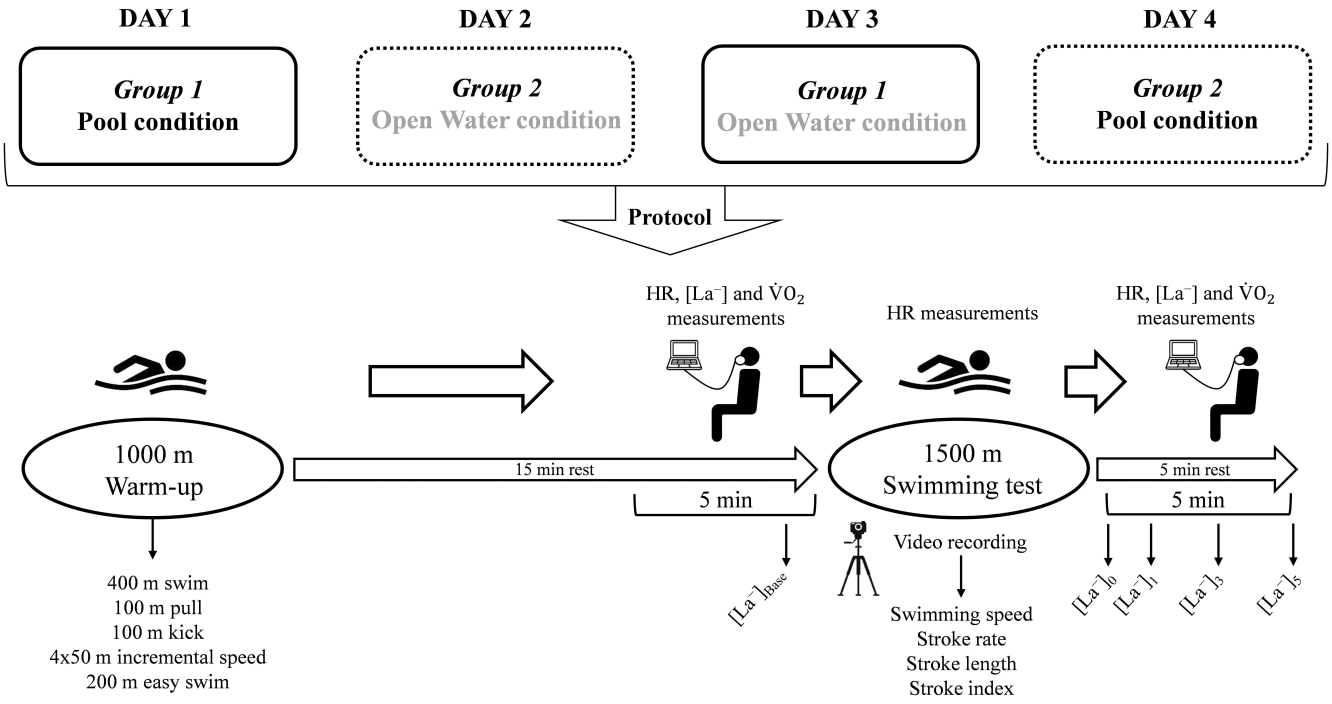

FIGURE 1 | Overview of the experimental study design. HR, heart rate; [La⁻], blood lactate concentration; $[La^-]_{Base}$, baseline blood lactate concentration; $[La^-]_0$, $[La^-]_1$, $[La^-]_3$, $[La^-]_5$, blood lactate concentration at 1, 3, and 5 min after the effort; $\dot{V}O_2$, oxygen uptake.

conditions, the camera was positioned on a side dock, 50 m to the side and 25 m ahead of the triathletes' starting position. In pool conditions, it was placed in the stands of the pool, at a water height of 7 m, and at a distance of 20 m from the swimmer. In both cases, the camera recorded with an optical zoom by following the triathlete, capturing a 7-m area with the triathlete centered in the image. Videos were analyzed on an in-house customized software for race analysis in competitive swimming by one expert evaluator [7]. The times (s) performed in the 1500 m swimming tests were obtained by video analysis. In addition, World Aquatics Points were used as a performance variable to standardize the times performed between male and female triathletes [7].

In open water conditions, the swimming speed ($m \cdot s^{-1}$) was measured as the time to cover the distance between the two competition buoys (i.e., 250 m), obtained from the moment the swimmers' head was next to the buoy and finished when the same position was reached at the next buoy (i.e., excluding buoy turn times). Moreover, the stroke rate (SR) was obtained by considering three upper limb cycles divided by the time elapsed during this action and multiplied by 60 to consider the number of cycles per minute. The SR was measured two times every 50 m of each lap (i.e., 10 times per 250 m) to obtain the mean SR in each 250 m lap. The stroke length (SL) was obtained from the ratio between the swimming speed and SR. The SI was calculated as the product of swimming speed and SL [19].

On the contrary, in pool conditions, the swimming speed ($m \cdot s^{-1}$) was calculated between 5–20 and 30–45 m marks every 50 m to avoid the push-off influence on the wall (i.e., excluding turn times). To standardize the comparison, swimming speed was computed for every 250 m lap as the average speed of 10 measurements as done in open water conditions. Finally, the same open water procedures were carried out to obtain the SR, SL, and SI [19]. In this case, each stroke variable (i.e., SR, SL, and SI) was computed by the average between the 5–20 and 30–45 every 50 m.

3.3 | Physiological Measurements

Respiratory gas exchange was measured breath by breath using a portable gas analyzer (Cosmed K5, Rome, Italy) during the 5 min before (baseline) and after the test in sitting position (i.e., off-kinetics) [17]. During recovery period, mask fitting was right after completing the last stroke of the test [17]. Prior to the tests, air, flowmeter, reference gas, scrubber, and time delay calibrations were performed following the manufacturers' recommendations. The off-kinetics response was modeled with VO_2FITTING, a free and open-source software [20] based on the R language (www.r-project.org, R Core Team 2015) with support of the "Shiny package" [21]. Raw data were used in all the cases. Bootstrapping with 1000 samples was used to estimate $\dot{V}O_2$ kinetics parameters. Besides, breath-by-breath data obtained during the 5 min of recovery were adjusted as a function of time using mono-exponential model by the following equation [20]:

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

where $\dot{V}O_2(t)$ represents the relative $\dot{V}O_2$ at the time t, $EE\dot{V}O_2$ is the $\dot{V}O_2$ at the end of exercise (i.e., 1500 m swimming test), H represents the Heaviside step function [22], and A_p, TD_p, and τ_p are the amplitude, time delay, and time constant of the $\dot{V}O_2$ fast

component [20]. The EE$\dot{V}O_2$ was estimated by backward extrapolation at zero recovery time using linear regressions applied to the first 20 s of recovery. Respiratory exchange ratio (RER) was obtained from the average of the first 20 s after the effort [23].

The HR was recorded using a Polar H10 sensor chest strap device (Polar Electro Oy, Kempele, Finland) during the test and during the 5 min before and after the effort in sitting position. HR recordings were exported from the Polar Flow website to an Excel spreadsheet. Then, mean baseline HR ($HR_{meanBase}$), mean HR during the test ($HR_{mean1500}$), maximum HR during the test ($HR_{max1500}$), and mean HR after the test ($HR_{meanPost}$) were obtained. In addition, the mean HR obtained every 250 m lap (i.e., HR_{250}, HR_{500}, HR_{750}, HR_{1000}, HR_{1250}, and HR_{1500}) in each triathlete was analyzed. Moreover, [La$^-$] were collected using a portable lactate analyzer (Lactate Pro 2.0, Arkray Inc., Japan) from the swimmers' right lobe 1 min prior to the test ($[La^-]_{Base}$), right after the effort ($[La^-]_0$), at min 1 ($[La^-]_1$), and every 2 min (i.e., at min 3 $[La^-]_3$ and 5 $[La^-]_5$) until the peak ($[La^-]_{peak}$) was reached. The $[La^-]_{net}$ was the difference between the $[La^-]_{Base}$ and $[La^-]_{peak}$. Moreover, Finally, rate of perceived exertion (RPE) was asked to the swimmers right after the test (0–10 scale) [24].

3.4 | Statistical Analyses

The normal distribution of the data was confirmed by the Shapiro–Wilk test. Paired sample *t*-test was used to compare differences between open water and pool swimming conditions for the mean value of each variable. Effect sizes (d) of the obtained differences were calculated and categorized as follow: small if $0 \leq |d| \leq 0.5$, medium if $0.5 < |d| \leq 0.8$, and large if $|d| > 0.8$ [25]. A two-way repeated measures ANOVA (condition × distance) was used to assess the effect of the 250 m laps on kinematic variables and HR during the test. The same analysis was replicated to examine the effect of the measurement time and [La$^-$] (condition × measurement time) after the swimming tests. Bonferroni post hoc test was used to compare between each pairwise and effect size was expressed as eta squared (η^2). Pearson's correlations were conducted in performance, kinematic and the main physiological variables (i.e., $HR_{mean1500}$, $HR_{max1500}$, $[La^-]_{peak}$ and EE$\dot{V}O_2$) to test the association between open water and pool swimming performance. The threshold correlation values were defined as: ≤0.1 trivial; <0.1–0.3 small; >0.3–0.5 moderate; >0.5–0.7 large; >0.7–0.9 very large; and >0.9–1.0 almost perfect [26]. The significance level was set up at $p < 0.05$, and all the statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS 28.0, IBM Corporation Chicago, IL, USA).

4 | Results

Mean, standard deviation (SD), and comparisons between the open water and pool swimming conditions are presented in Table 1. Swimming performance declined in open water compared with pool conditions (Table 1). Lower swimming speed, SL, and SI were obtained in open water compared with pool, whereas a higher SR was reached in open water. Regarding physiological variables, no differences were found in HR, [La$^-$] and EE$\dot{V}O_2$ between conditions. Instead, lower RER and higher τ_p were obtained in open water compared with pool swimming (Table 1). The two-way repeated measures ANOVA revealed a condition (i.e., open water and pool) main effect in swimming speed ($p < 0.001$; $\eta^2 = 0.939$), SR ($p = 0.005$; $\eta^2 = 0.474$), SL ($p < 0.001$; $\eta^2 = 0.843$), and SI ($p < 0.001$; $\eta^2 = 0.878$) (Figure 2). However, no differences were found in HR ($p = 0.818$; $\eta^2 = 0.006$; Figure 3) and [La$^-$] ($p = 0.350$; $\eta^2 = 0.088$; Figure 4). There was a distance (i.e., 250 m laps)/measurement time (i.e., $[La^-]_{Base,\ 1,\ 3}$ and $_5$) main effect in swimming speed ($p < 0.001$; $\eta^2 = 0.918$), SR ($p = 0.021$; $\eta^2 = 0.727$), SL ($p < 0.001$; $\eta^2 = 0.915$), SI ($p < 0.001$; $\eta^2 = 0.964$) (Figure 2), HR ($p < 0.001$; $\eta^2 = 0.962$; Figure 3), and [La$^-$] ($p < 0.001$; $\eta^2 = 0.910$; Figure 4). There was an interaction between condition and distance in swimming speed ($p = 0.002$; $\eta^2 = 0.835$). No other significant interaction between condition and distance/time was observed ($p > 0.05$). The associations between open water and pool swimming of performance and kinematic, and physiological variables are presented in Figures 5 and 6, respectively.

5 | Discussion

The aims of the current study were to compare performance, kinematic, and physiological variables between the 1500 m open water and pool swimming conditions and to examine the associations between conditions on these variables. As it was hypothesized, swimming performance and kinematics were negatively affected by the open water condition. On the other hand, contrary to the initial hypothesis, the physiological demands were similar in both conditions, where HR, [La$^-$] and EE$\dot{V}O_2$ did not differ between open water and pool swimming. The fastest triathletes in open water obtained the best performance in the swimming pool. All kinematic variables, $HR_{mean1500}$, $HR_{max1500}$, and $[La^-]_{peak}$ presented positive associations between open water and pool swimming.

The external conditions inherent to open water swimming have an overall impact on swimmers' performance [8], which contributed to the higher times and lower swimming speeds (Table 1, Figure 2) obtained in the 1500 m open water compared with those achieved in the pool. Moreover, the actual distance covered in open water [27] or swimming continuously without turns and push-offs performed in pool conditions [7] may explain the higher time and lower speed obtained in the 1500 m open water swimming. On the contrary, despite environmental differences, previous studies showed positive relationships between open water an pool swimming performance in both swimmers and triathletes [10, 12]. This is consistent with the positive associations found in the current study, indicating that the fastest triathletes in open water also achieved the best performance in pool swimming conditions (Figure 5). Therefore, in terms of performance or swimming speed, triathletes may improve in both open water and pool conditions, as these are highly positively associated despite their different environments.

Triathletes increased SR at the expense of SL in open water compared with pool conditions to maintain swimming speed, as observed in the mean values (Table 1) and between 250 m laps during the tests (Figure 2). However, the SR changes could not compensate for the decrease in SL, leading to a lower speed in open water (Table 1, Figure 2). In that sense, although swimmers could either increase SR or SL for maintaining speed [28] the open water conditions (e.g., coping with currents or looking

TABLE 1 | Mean ± SD values for open water and pool swimming conditions in elite triathletes ($n = 14$), 95% confident interval (95% CI) and p values (paired sample t-test) with effect size (d) for performance, kinematic, and physiological variables.

	Open Water	Pool		
Variables	**Mean ± SD**	**Mean ± SD**	**Difference [95%CI]**	***p* value (*d*)**
Performance variables				
$Time_{1500}$ (s)	1246.95 ± 68.26	1118.29 ± 61.54	128.66 [117.18, 140.13]	<0.001* (1.98)
World Aquatics Points	360 ± 45	469 ± 46	−109 [−120, −98]	<0.001* (2.10)
Kinematic variables				
Swimming speed ($m \cdot s^{-1}$)	1.21 ± 0.06	1.28 ± 0.07	−0.07 [−0.07, −0.06]	<0.001* (1.07)
SR ($cycles \cdot min^{-1}$)	40.43 ± 2.68	39.52 ± 2.83	0.91 [0.32, 1.47]	0.002* (0.33)
SL (m)	1.80 ± 0.14	1.95 ± 0.18	−0.15 [−0.18, −0.11]	<0.001* (0.93)
SI ($m^2 \cdot s^{-1}$)	2.19 ± 0.24	2.50 ± 0.33	−0.31 [−0.38, −0.24]	<0.001* (1.07)
Physiological variables				
$HR_{meanBase}$ ($beats \cdot min^{-1}$)	78 ± 17	76 ± 11	2 [−6, 12]	0.246 (0.21)
$HR_{mean1500}$ ($beats \cdot min^{-1}$)	166 ± 10	168 ± 8	−2 [−2, 2]	0.470 (0.00)
$HR_{max1500}$ ($beats \cdot min^{-1}$)	175 ± 10	177 ± 9	−2 [−4, 1]	0.066 (0.21)
$HR_{meanPost}$ ($beats \cdot min^{-1}$)	115 ± 10	113 ± 12	2 [−2, 8]	0.129 (0.27)
$[La^-]_{peak}$ ($mmol \cdot L^{-1}$)	7.47 ± 1.80	7.76 ± 2.13	−0.29 [−1.33, 0.74]	0.275 (0.15)
$[La^-]_{net}$ ($mmol \cdot L^{-1}$)	5.20 ± 1.75	5.66 ± 2.01	−0.46 [−1.54, 0.61]	0.184 (0.24)
$EE\dot{V}O_2$ ($mL \cdot kg^{-1} \cdot min^{-1}$)	54.60 ± 7.81	57.72 ± 10.51	−3.12 [−10.07, 3.83]	0.175 (0.16)
RER	1.01 ± 0.12	1.08 ± 0.16	−0.07 [−0.12, −0.02]	0.005* (0.24)
A_p ($mL \cdot kg^{-1} \cdot min^{-1}$)	44.74 ± 7.5	45.37 ± 9.99	−0.63 [−7.03, 5.78]	0.418 (0.07)
TD_p (s)	6.35 ± 8.39	4.90 ± 5.81	1.45 [−3.72, 6.61]	0.278 (0.20)
τ_p (s)	43.20 ± 9.48	39.07 ± 9.34	4.13 [−0.29, 8.55]	0.032* (0.44)
RPE	9.57 ± 0.64	9.29 ± 0.99	0.28 [−0.19, 0.76]	0.109 (0.34)

Abbreviations: $[La^-]_{net}$, lactate concentration difference between the $[La^-]_{Base}$ and $[La^-]_{peak}$; $[La^-]_{peak}$, peak blood lactate concentration; A_p, TD_p and τ_p, amplitude, time delay and time constant of the oxygen uptake fast component; $EE\dot{V}O_2$, end-exercise oxygen uptake; $HR_{max1500}$, maximum heart rate during the test; $HR_{mean1500}$, mean heart rate during the test; $HR_{meanBase}$, mean baseline heart rate; $HR_{meanPost}$, mean heart rate after the test; RER, respiratory exchange ratio; RPE, rate of perceived exertion; SR, SL and SI, stroke rate, length and index; $Time_{1500}$, time performed in the 1500 m test.
*$p < 0.05$.

at the buoys for orientation) influence swimming kinematics [8, 9]. Regarding changes as a function of distance in open water, the SR was higher in the first and last 250 m laps than in the intermediate ones, as a consequence of a fast start [18] and the compensation for a loss of SL in the last meters [28]. In fact, the SL decrease was observed throughout the tests in each condition, probably evoked by the fatigue induced throughout the tests [29]. Moreover, the odd laps in open water were influenced by a current in favor of the course, where the triathletes increased their SL [9]. Besides, as a consequence of the reductions in swimming speed and SL, SI also declined in open water compared to pool (Table 1) and decreased throughout the tests in each condition (Figure 2). In this regard, given the negative association between SI and energy expenditure [19], SI impairments may imply a loss of efficiency. Hence, the decline in SI observed during the open water indicates that triathletes are less efficient in the natural environment. On the contrary, the positive associations observed between the two conditions across all kinematic variables (Figure 5) suggest that all triathletes adjusted their swimming technique similarly to adapt to fluctuating open water conditions. This adjustment entailed an increase in SR and a decrease in SL compared with pool swimming, thus specific open water swimming technique must be considered by triathletes and coaches.

Physiological responses vary depending on the swimming environment [11]. However, the main physiological variables analyzed in the current study (HR, $[La^-]$, and $EE\dot{V}O_2$) did not show differences between open water and pool conditions (Table 1, Figures 3 and 4). In addition, the similar behavior between conditions in both HR (Figure 3) and $[La^-]$ (Figure 4) during and after the tests emphasizes the substantial invariance of physiological variables. In that sense, as triathletes were asked to complete the tests at race pace [18], similar physiological responses were obtained, which was supported by the similar RPE values (Table 1). Contrary to previous findings where swimmers' HR and $\dot{V}O_2$ were affected by the open water fluctuations [11], it seems that elite triathletes are able to sustain the same submaximal effort despite the different swimming conditions and kinematics in both environments. In this regard, it is important to

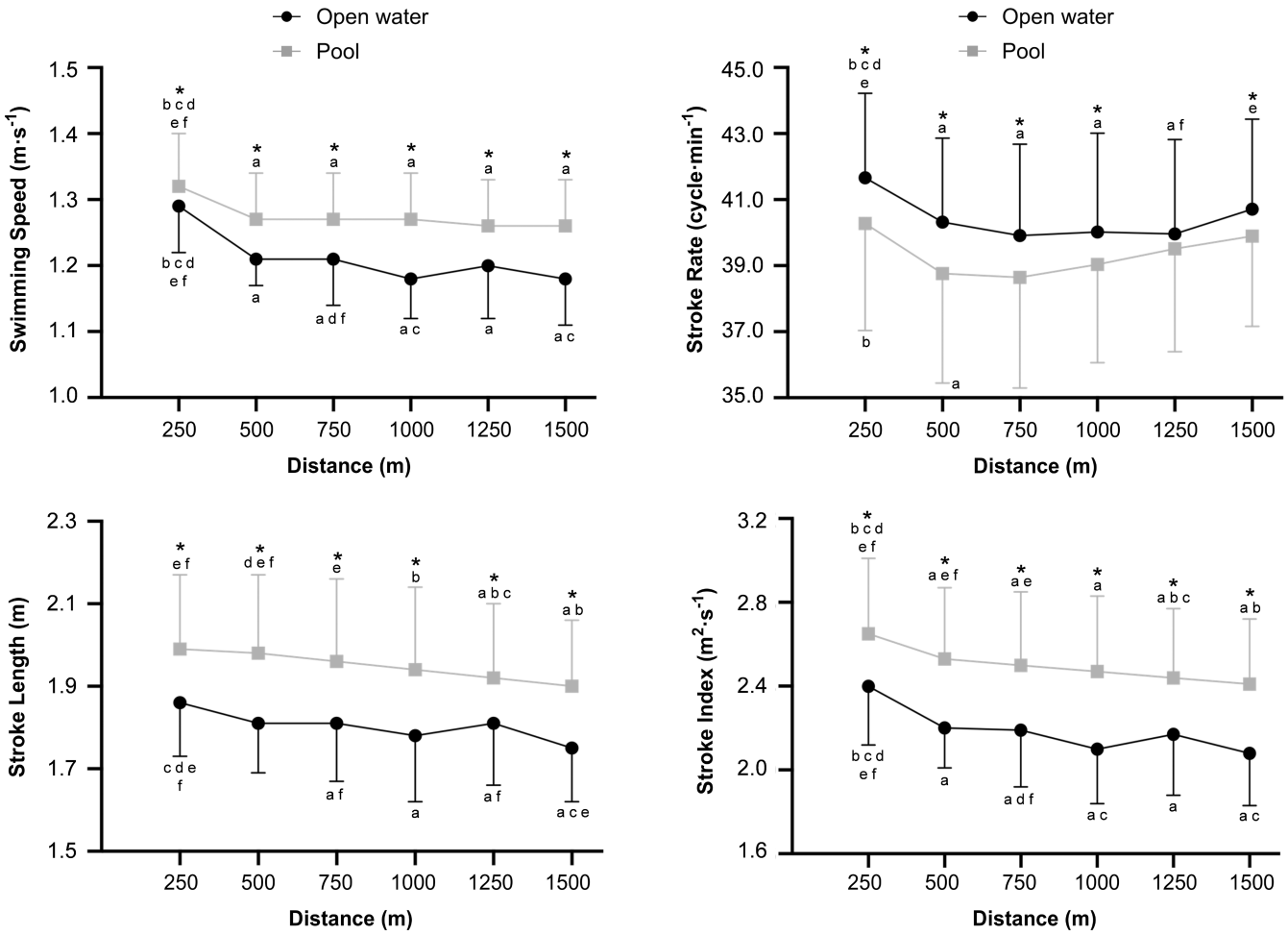

FIGURE 2 | Mean and standard deviation of kinematic variables analyzed every 250 m lap during the 1500 m swimming tests in elite triathletes ($n = 14$). *Differences ($p < 0.05$) between open water and pool conditions in each 250 m lap. Different letters represent the differences ($p < 0.05$) between 250 m laps in each condition according Bonferroni post hoc test: a, b, c, d, e, and f show the difference with the first, second, third, fourth, fifth, and sixth 250 m lap, respectively.

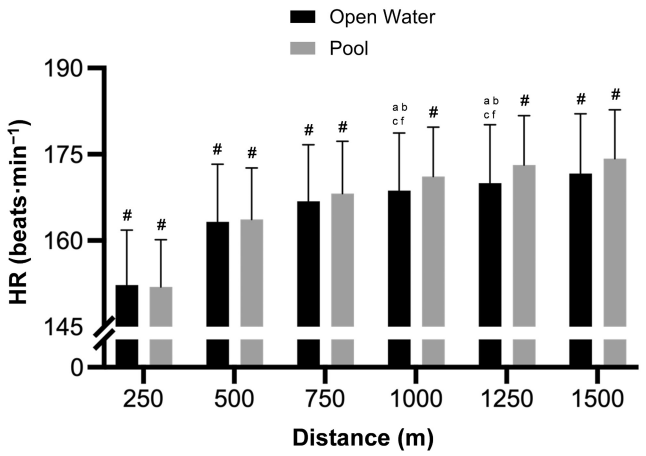

FIGURE 3 | Comparison in mean heart rate (HR) for each 250 m lap between open water and pool swimming conditions in elite triathletes ($n = 14$). Different letters represent the differences ($p < 0.05$) between 250 m laps in each condition according Bonferroni post hoc test: a, b, c, and f show the difference with the first, second, third, and sixth 250 m lap, respectively. # Difference ($p < 0.05$) with all 250 m laps in each condition.

note the athletes' performance level and experience of training and competition in open water condition, as this may trigger similar responses to those obtained in the pool. On the contrary, the few physiological differences between both swimming conditions were reflected by the higher RER obtained in the pool compared to open water conditions (Table 1). These differences indicate a predominant use of carbohydrates in pool compared with the lower RER obtained in open water, suggesting a higher contribution of lipids in the natural environment [30]. In this regard, the longer duration of the open water test may explain the lower RER values and different energy demands (i.e., increased lipid oxidation) obtained compared with pool swimming. In addition, the lower τ_p observed in swimming pool conditions (Table 1) may indicate a faster physiological response compared to open water [31], probably due to the more stable pool conditions, which allowed an earlier cardiovascular and muscular systems adaptation to the effort.

Besides, the positive associations found in $HR_{mean1500}$, $HR_{max1500}$, and $[La^-]_{peak}$ between open water and pool swimming demonstrated similar physiological responses in the two environments (Figure 6). Instead, no significant relationships were found among

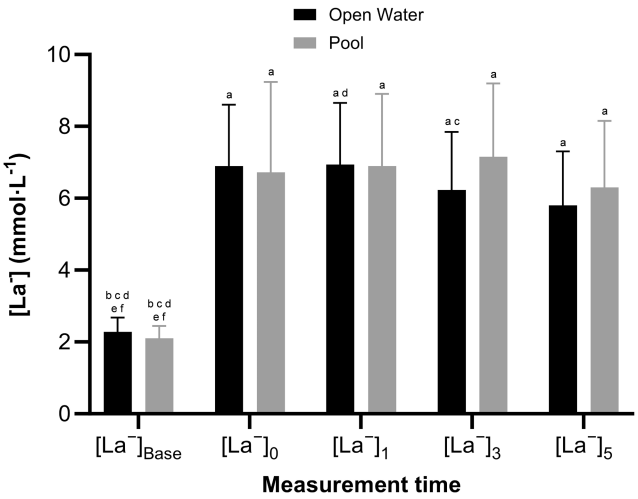

FIGURE 4 | Comparison in blood lactate concentrations [La⁻] between open water and pool swimming conditions in elite triathletes ($n = 14$). $[La^-]_{Base}$, baseline blood lactate concentration; $[La^-]_0$, $[La^-]_1$, $[La^-]_3$, $[La^-]_5$, blood lactate concentration immediately after the effort, and 1 one, 3 and 5 min after. Different letters represent the differences ($p < 0.05$) between measurement times in each condition according Bonferroni post hoc test: a, b, c, d, e, and f show the difference with the $[La^-]_{Base}$, $[La^-]_0$, $[La^-]_1$, $[La^-]_3$, and $[La^-]_5$, respectively.

open water and pool conditions in EE$\dot{V}O_2$. In that sense, the interaction and contribution of the energy systems depends on the duration, intensity and mode of exercise [32]. Hence, the longest durations (i.e., times performed) and pace changes (i.e., swimming speed variations) (Figure 2) in open water compared to pool swimming may modify the energy contributions and, as a consequence, alterations in the $\dot{V}O_2$ kinetics. In addition, although the mode of locomotion is the same, open water environment and its swimming kinematic differences, may also cause these alterations in EE$\dot{V}O_2$ [11]. Therefore, knowing the differences in competitive and usual training environments, coaches and triathletes might this into account for planning specific training sessions to simulate the experience of open water swimming.

In general terms, coinciding with previous studies in swimmers [8] and triathletes [7], the results obtained seem to indicate that a technical enhancement (i.e., kinematic variables) has more effects on swimming performance than the improvement in physiological variables in elite triathletes. The current study presents some interesting and novel results for triathletes and coaches; however, it was limited by the small sample size. Further studies should consider larger sample sizes with different performance levels and dividing the results by sex. On the contrary, it is important to highlight the high level and the control over the sample, since triathletes belong to the same team. Another limitation is the real

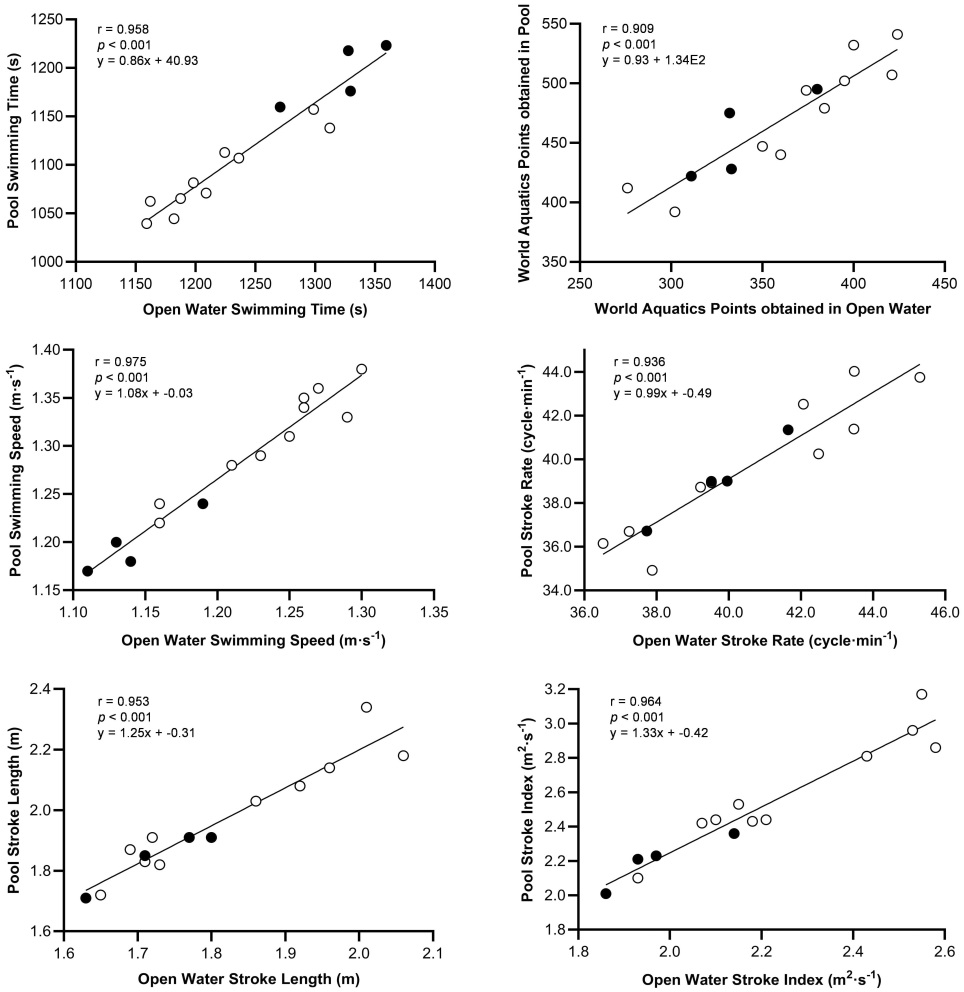

FIGURE 5 | Correlations between open water and pool swimming performance and kinematic variables in elite triathletes. White (○) and black (●) dots represent males ($n = 10$) and females ($n = 4$), respectively.

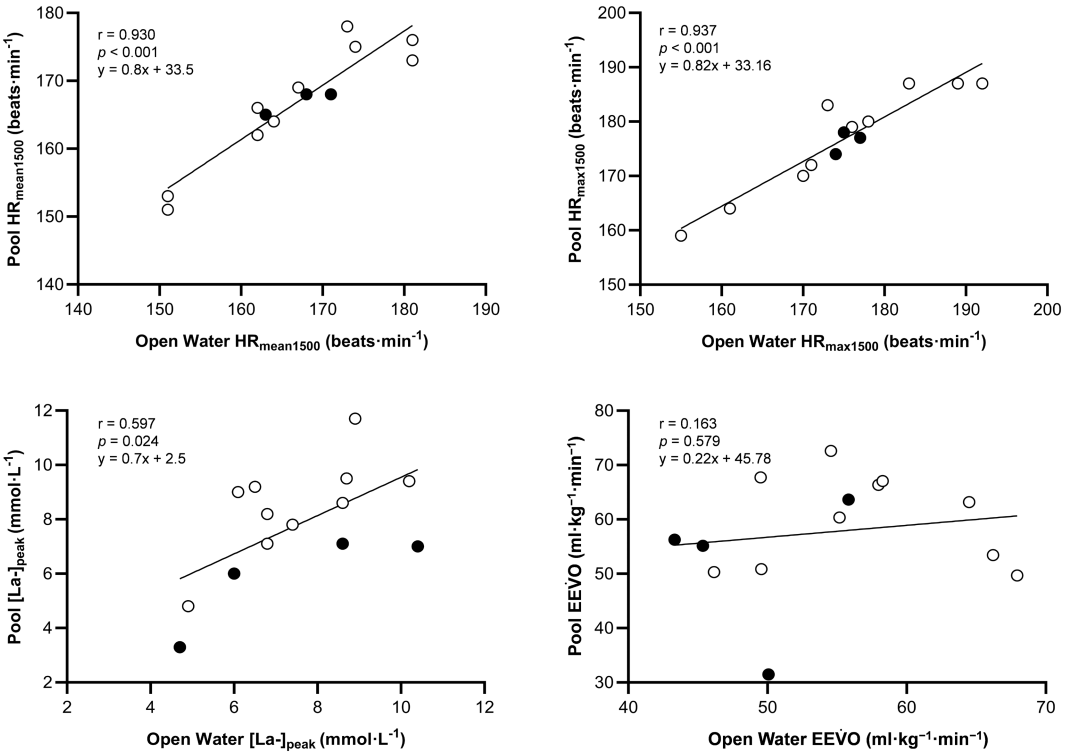

FIGURE 6 | Correlations between open water and pool swimming physiological variables in elite triathletes. White (○) and black (●) dots represent males ($n = 10$) and females ($n = 4$), respectively. $HR_{mean1500}$, mean heart rate during the test; $HR_{max1500}$, maximum heart rate during the test; $[La^{-}]_{peak}$, peak blood lactate concentration; $EE\dot{V}O_2$, end-exercise oxygen uptake.

distance covered in open water by each triathlete, which was not measured and might affect the results obtained. Nevertheless, the characteristics of the open water course in a straight line facilitated the triathletes' orientation in the current study.

6 | Perspectives

The analysis of physiological variables linked to kinematics in competitive and usual training contexts is essential in sports. Given the crucial role of swimming as the first section in a triathlon competition and its influence on performance, a deeper knowledge about this discipline may lead to more specific training plans. The main findings showed that swimming kinematics is affected by the open water conditions. Based on these results, triathletes must perform specific training sessions to adapt their technique to the changing open water conditions. Moreover, during the process of kinematic adaptation physiological responses should be monitored to gain knowledge about its demands or enhancements. In this way, triathletes would be able to maximize the swimming efficiency in the competitive environment. Finally, the development of pacing strategies based on the quantification of kinematic variables (e.g., SR) could be a useful and easy tool to apply in a training context.

7 | Conclusions

The open water conditions had an impact on performance leading to lower swimming speed and changes in kinematic variables. However, these influences were similar for all swimmers, as the fastest in open water were also the fastest in pool swimming and kinematic variables displayed positive associations between conditions. With regard to physiological variables, the substantial invariance between open water and pool conditions showed similar demands in both environments.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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