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Research article

A study of triathletes' race strategies in different competition environments

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ABSTRACT

What is known, sports performance is impacted by a variety of factors. While most people understand the importance of training, proper nutrition, and adequate rest, not as many recognize the impact of environmental factors on athletic performance. This paper investigates the race strategies of Chinese triathletes in different competition environments, with a focus on the performance of professional triathletes during the Olympic Distance Triathlon held in China between 2015 and 2021. Data from 984 athletes who competed in 26 races were analyzed to evaluate the sensitivity of the three splits of swimming, cycling, and running to overall triathlon performance under different temperature (low, normal, and high), altitude (low, normal, and high), and waters (sea, river, and still waters) conditions. Results show that the effects of the three split times on overall time vary across different environments. Cycling has the greatest impact on overall performance when the temperature is suitable (at low temperature, at normal temperature) and the altitude is suitable (at low altitude, at normal altitude). While running has the greatest impact in high-temperature and high-altitude environments. For female athletes, in river waters, swimming has a greater effect on overall performance than cycling, but less than running. These findings provide practical suggestions for athletes, coaches, and competition organizers to optimize training and race strategies based on specific environmental conditions.

1. Introduction

Triathlon is an integrative sport that combines swimming, cycling, and running, and it has gained increasing popularity worldwide over the last few decades. Due to its multidisciplinary nature and demands on various race skills, athletes face unique challenges in terms of endurance, injuries, physiological adaptations, and strategic planning [1]. Competitors participate in various racing formats, including Sprint, Olympic-distance, half-Ironman, and Ironman distances, each necessitating different training and race tactics [2]. The Olympic distance triathlon include 1.5 km of swimming, 40 km of bicycling, and 10 km of long-distance running [3].

Scholars have studied the factors affecting athlete performance in Triathlon. Millet and colleagues identified in their study the relationship between the training volume and athlete performance in Triathlon [4]. They found that the training volume of long-distance running is significantly related to running performance and overall performance. Deng found that in Triathlon, the contribution of running to overall performance was the largest compared with other splits in Triathlon [5]. The degree of correlation between splits influenced the training arrangement and effect. The correlations between running and cycling, swimming and cycling

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were both significant, while the correlation between swimming and running was not significant. Therefore, in Triathlon, the split following swimming or cycling can be beneficial during the race [6]. There are several environmental factors that can impact triathlon pacing, such as waters currents, wind conditions, topography, ambient heat, and humidity [7]. Studies should consider the role of course characteristics and environmental conditions in the relationship between overall and split times in triathletes [8].

At present, Chinese triathletes are receiving improved training on national and local levels for greater performance [9], but there is still a gap between them and high-performing international athletes in order to win gold and silver metals. Fan and Liu evaluated the overall performance, single race performance, and performance improvement among outstanding Chinese and international female triathletes [[10,11]]. Through comparative analysis, they found that there is a gap between the Chinese and the world female triathletes regarding overall performance. In the single performances of swimming, cycling, and performance change, Chinese and international female triathletes performed approximately at the same level. In cross-country running, however, international female triathletes performed considerably better than Chinese female triathletes. There has been a burgeoning interest in the sport in China recently [12]. However, empirical studies on Chinese triathletes are limited.

This paper aims to contribute to the existing research on triathlon by investigating the race strategies of Chinese triathletes in different competition environments, with a specific focus on the performance of Chinese professional triathletes during the Olympic Distance Triathlon held in China between 2015 and 2021. The research objective is to provide novel insights into the sport in China and offer practical suggestions for Chinese triathletes and coaches seeking to optimize their training and race strategies.

2. Methods and materials

2.1. Data

To conduct this study, we analyzed race results from 984 athletes who competed in 26 Olympic distance Triathlon races held in China between 2015 and 2021. The dataset included 617 race results from male athletes and 367 race results from female athletes. We obtained the race data from the official website of the Chinese Triathlon Association (http://triathlon.basts.com.cn/#home).

To determine the impact of environmental factors on triathletes' performance, we collected environmental data from the official website. Temperature data was obtained from the official historical weather website (https://lishi.tianqi.com/). Specifically, we used the highest temperature recorded on the race day was used as the temperature data, and we obtained the elevation of the main race venue was obtained as the elevation data. By analyzing these environmental factors, we were able to evaluate their impact on triathletes' overall performance in the races.

3. The Kruskal-Wallis test

The Kruskal-Wallis (Kruskal & Wallis, 1952) is a nonparametric statistical test that assesses the differences among three or more independently sampled groups on a single, non-normally distributed continuous variable. Non-normally distributed data (e.g., ordinal or rank data) are suitable for the Kruskal-Wallis test. In contrast, the one-way analysis of variance (ANOVA), which is a parametric test, may be used for a normally distributed continuous variable. The Kruskal-Wallis test is an extension of the two-group Mann-Whitney U (Wilcoxon rank) test. Thus, the Kruskal-Wallis is a more generalized form of the Mann-Whitney *U* test and is the nonparametric version of the one-way ANOVA.

The test statistic for one-way analysis of variance is calculated as the ratio of the treatment sum of squares to the residual sum of squares. The Kruskal-Wallis test uses the same method but, as with many nonparametric tests, the ranks of the data are used in place of the raw data.

The test statistic is calculated according to Eq. (1):

$$T = \frac{12}{N(N+1)} \sum_{j=1}^{k} \frac{R_j^2}{n_j} - 3(N+1) \tag{1}$$

where R_j is the total of the ranks for the j th sample, n_j is the sample size for the j th sample, k is the number of samples, and N represents the total sample size as given by Eq. (2):

$$\sum_{j=1}^{k} n_j \tag{2}$$

This is approximately distributed as a χ^2 distribution with k - 1 degrees of freedom. Where there are ties within the data set the adjusted test statistic is calculated as shown in Eq. (3):

$$T = \frac{1}{S^2}\left(\sum_{j=1}^{k} \frac{R_j^2}{n_j} - \frac{N(N+1)^2}{4} \right) \tag{3}$$

Where r_{ij} is the rank for the ith observation in the jth sample, n_j is the number of observations in the jth sample, and S^2 is determined by the formula in Eq. (4):

$$S^2 = \frac{1}{N-1}\left(\sum_{j=1}^{k}\sum_{i=1}^{n_j} r_{ij}^2 - \frac{N(N+1)^2}{4}\right) \tag{4}$$

3.1. Sensitivity analysis

Sensitivity analysis is a method to quantitatively analyze the effect of parameters on the model output results. In the study, we analyzed the athletes' race strategies by performing sensitivity analyses of the athletes' swimming performance, cycling performance, and running performance with respect to overall performance.

For linear trends, valid linear relationship measures are Pearson correlation coefficients (CCs), partial correlation coefficients (PCCs), and standardized regression coefficients (SRCs). For nonlinear monotonic relationships between outputs and inputs, valid measures are based on rank transformations such as Spearman's rank correlation coefficient (RCC or Spearman's rho), partial rank correlation coefficient (PRCC), and standardized rank regression coefficient (SRRC).

(1) PCC (partial correlation coefficient): The partial correlation coefficients of x_i and y are calculated between the residuals $(x_j - \widehat{x}_j)$ and $(y - \widehat{y})$, where $\widehat{x}_j$ and $\widehat{y}$ are obtained by linear regression as described in Eq. (5):

$$\widehat{x}_j = c_0 + \sum_{\substack{p=1 \\ p\neq j}}^{k} c_p x_p \text{ and } \widehat{y} = b_0 + \sum_{\substack{p=1 \\ p\neq j}}^{k} b_p x_p \tag{5}$$

where $x_p p = 1, 2, \cdots, k$, are the individual variables.

(2) RCC (rank correlation coefficient, i.e. Spearman correlation coefficient): The rank correlation coefficient between x_i and y is calculated between the rank data $\widehat{x}_i$ and $\widehat{y}$ after ranking the original data as illustrated in Eq. (6). For example:

Raw data		Rank-transformed data					
X_i	Y	X_i	Y	Order x_i	Order y	d_i	d_i^2
106	7	86	0	1	1	0	0
86	0	97	20	2	6	−4	16
100	27	99	28	3	8	−5	25
101	50	100	27	4	7	−3	9
99	28	101	50	5	10	−5	25
103	29	103	29	6	9	−3	9
97	20	106	7	7	3	4	16
113	12	110	17	8	5	3	9
112	6	112	6	9	2	7	49
110	17	113	12	10	4	6	36

$$RCC = 1 - \frac{6\sum d_i^2}{n(n^2-1)} \text{ or } RCC = \frac{\sum_i (x_i - \overline{x})(y_i - \overline{y})}{\sqrt{\sum_i (x_i - \overline{x})^2}\sqrt{\sum_i (y_i - \overline{y})^2}} \tag{6}$$

The calculation gives $RCC = -0.175$.

(3) PRCC is a biased correlation of the rank-transformed data: first, the rank transformation of x_j and y is performed, i.e., the original data is converted into rank data, and then the linear regression of the model is built according to Eq. (7):

$$\widehat{x}_j = c_0 + \sum_{\substack{p=1 \\ p\neq j}}^{k} c_p x_p \text{ and } \widehat{y} = b_0 + \sum_{\substack{p=1 \\ p\neq j}}^{k} b_p x_p \tag{7}$$

where $x_p, p = 1, 2, \cdots, k$ is the individual variable.

The PRCC is obtained by calculating the correlation coefficient from the obtained data according to Eq. (8):

$$prcc = \frac{Cov\left(x_j - \widehat{x}_j, y - \widehat{y}\right)}{\sqrt{Var\left(x_j - \widehat{x}_j\right) Var(y - \widehat{y})}} \tag{8}$$

where $Cov(x_j, y)$ is the covariance between x_j and y, while $Var(x_j)$ and $Var(y)$ are the variances of x_j and y respectively.

4. Results

The data distribution by gender was found to be non-normal, so we chose the Kruskal-Wallis test. The results of Kruskal-Wallis test for male and female athlete are in Tables 1 and 2. For male athletes, the Kruskal-Wallis test was employed to compare overall time across different temperature groups, altitude groups, and waters groups, and all of them exhibited statistically significant differences ($p < 0.05$). In contrast, for female athletes, the Kruskal-Wallis test was used to compare total seconds across different temperature groups, altitude groups, and waters groups. It was found that only cycling performance at different temperatures and running performance at different altitudes did not show any significant differences ($p > 0.05$).

Take the waters as an example. The Kruskal-Wallis test was conducted to compare the overall in seconds for male athletes among three water types: still water, river water, and sea water. The H-statistic was 25.22, with a significant p-value of 0.0000 (see Table 1), indicating the presence of significant differences among the water types. Pairwise comparisons were conducted using Mann-Whitney U tests were performed to examine the differences between each pair of water types. The p-values for the pairwise comparisons were as follows: 0.0076 for the comparison between still water and river water, approximately 0.0000 for the comparison between still water and sea water, and 0.4714 for the comparison between river water and sea water. To account for multiple comparisons, the Bonferroni adjustment was applied to adjust the p-values. The Bonferroni-adjusted p-values were 0.0228, approximately 0.0000, and 1.0000 for the aforementioned comparisons, respectively. These results suggest a significant difference between still water and sea water, a significant difference between river water and sea water, but no significant difference between still water and river water after Bonferroni adjustment was applied.

4.1. *Effects of temperature change on athlete performance*

In order to analyze the effect of temperature on each type of performance, we divided the temperature into three stages: low temperature (less than 25 °C), normal temperature (greater than or equal to 25 °C but less than 30 °C), and high temperature (greater than or equal to 30 °C), and analyzed the relationship between temperature and each split under different stages. Firstly, through statistical methods, we obtained the arithmetic mean, median, and weight of each performance of men and women at different temperatures (as shown in Table 3).

Swimming, cycling, running, and overall correspond to the times for swimming, cycling, running, and overall events, respectively, in seconds. The results showed that the athletes' performances demonstrated a slight trend of improvement with the decrease in temperature, among which the running performance improved more.

To further analyze the effect of temperature on each performance, we calculated the PRCC of each performance and the overall performance for men and women at different temperatures by the method proposed by Conover (1999), and the results are shown in Table 4 and Fig. 1((a)-(b)).

For example, the PRCCs of men's swimming, cycling, and running for overall performance at low temperature were 0.47, 0.95, and 0.85, respectively. These results indicate that for the same time reduction in swimming, cycling, and running, the largest to smallest time decreases on overall performance were cycling, running, and swimming. It can also be found that with the change in temperature, the influence of men's swimming performance on overall performance changes more, but the degree of influence is always smaller than the influence of cycling and running on overall performance. For female triathletes, the influence of swimming on overall performance also changes more and shows an increasing trend, but the degree of influence is always smaller than the influence of cycling and running on overall performance. The difference is that in the case of high temperatures, the effect of running on overall performance is greater than that of cycling.

4.2. *Effects of altitude change on athlete performance*

In order to analyze the effect of altitude on each performance, we divided altitude into three stages: low altitude (less than 100 m), normal altitude (greater than or equal to 100 m and less than 1000 m), and high altitude (greater than or equal to 1000 m), and analyzed the relationship between altitude and each performance under different stages.

Through statistical method, we obtained the arithmetic mean, median, and weight of each performance for men and women at different altitudes (see Table 5). Results in Table 5 show that with the increase in altitude, the athletes' cycling is gradually improving, and the performance of athletes shows a slight upward trend, among which the performance of running changes more. Regardless of the elevation increase or decrease, the athletes' performance consistently improved. Similarly, we calculated the PRCC of each item

Table 1
Kruskal-Wallis test results for male athletes.

Variables	Swimming		Cycling		Running		Overall	
	H-statistic	P-value (after Bonferroni adjustment)	H-statistic	P-value (after Bonferroni adjustment)	H-statistic	P-value (after Bonferroni adjustment)	H-statistic	P-value (after Bonferroni adjustment)
Temperature	105.49	0.0000	6.93	0.0313	134.67	0.0000	33.01	0.0000
Altitude	35.06	0.0000	25.61	0.0000	23.88	0.0000	9.76	0.0076
Waters	49.06	0.0000	93.35	0.0000	56.43	0.0000	25.22	0.0000

Table 2
Kruskal-Wallis test results for female athletes.

Variables	Swimming		Cycling		Running		Overall	
	H-statistic	P-value	H-statistic	P-value	H-statistic	P-value	H-statistic	P-value
Temperature	14.06	0.0009	1.33	0.5140	91.32	0.0000	7.67	0.0216
Altitude	22.59	0.0000	16.91	0.0002	1.77	0.4124	15.92	0.0003
Waters	7.09	0.0289	12.70	0.0017	51.83	0.0000	31.29	0.0000

Table 3
Results of each split and overall performance at different temperatures.

			Swimming	Cycling	Running	Overall
Women	high temperature	Arithmetic mean/s	1226.99 ± 26.11	4211.54 ± 596.12	2519.28 ± 241.89	8052.92 ± 819.22
		Median/s	1227.00	3939.00	2451.00	7685.50
		Weights	15.24 %	52.30 %	31.28 %	100.00 %
	normal temperature	Arithmetic mean/s	1240.11 ± 63.55	4230.23 ± 430.51	2455.17 ± 219.99	8044.96 ± 553.66
		Median/s	1218.00	4043.50	2411.00	7844.50
		Weights	15.41 %	52.58 %	30.52 %	100.00 %
	low temperature	Arithmetic mean/s	1237.49 ± 40.39	4074.99 ± 330.03	2361.14 ± 196.57	7789.37 ± 470.4
		Median/s	1240.00	3926.00	2314.00	7671.00
		Weights	15.89 %	52.31 %	30.31 %	100.00 %
Men	high temperature	Arithmetic mean/s	1148.32 ± 39.78	3770.94 ± 513.19	2293.61 ± 224.9	7298.98 ± 722.23
		Median/s	1147.50	3609.50	2233.00	7075.50
		Weights	15.73 %	51.66 %	31.42 %	100.00 %
	normal temperature	Arithmetic mean/s	1163.53 ± 67.11	3771.52 ± 346.01	2154.63 ± 194.5	7193.73 ± 469.1
		Median/s	1149.50	3694.00	2113.00	7094.00
		Weights	16.17 %	52.43 %	29.95 %	100.00 %
	low temperature	Arithmetic mean/s	1131.46 ± 83.09	3674.98 ± 328.7	2096.8 ± 203.1	7020.94 ± 501.33
		Median/s	1118.00	3593.00	2063.00	6975.00
		Weights	16.12 %	52.34 %	29.87 %	100.00 %

Table 4
PRCC for split and overall results at different temperatures.

		Low temperature	normal temperature	High temperature
Men	Swimming	0.47	0.65	0.21
	Cycling	0.95	0.96	0.92
	Running	0.85	0.88	0.91
Women	Swimming	0.22	0.27	0.47
	Cycling	0.94	0.96	0.86
	Running	0.85	0.86	0.87

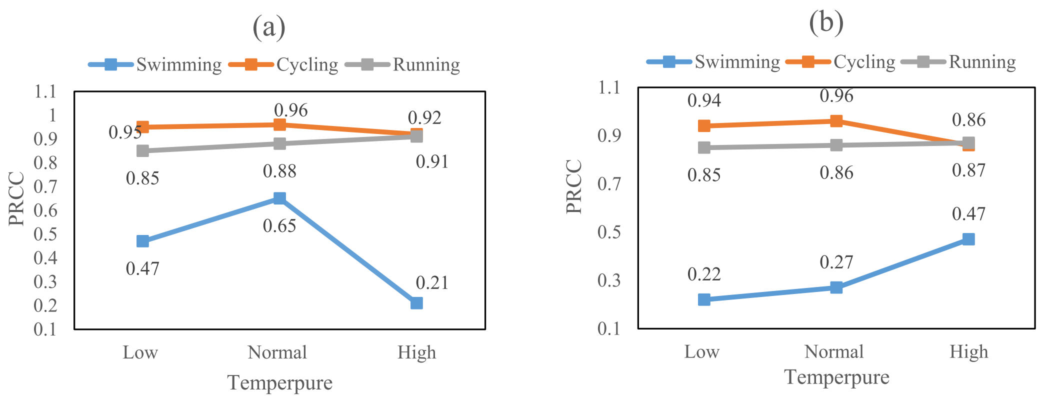

Fig. 1. The PRCC of each performance and the overall performance for men (a) and women (b) at different temperatures.

Tables 5
Results for each split performance at different altitudes.

			Swimming	Cycling	Running	Overall
Men	High Altitude	Arithmetic mean/s	1169.02 ± 35.64	3521.57 ± 152.41	2219.44 ± 164.29	6977.11 ± 303.52
		Median/s	1161.00	3459.00	2185.00	6898.50
		Weights	16.76 %	50.47 %	31.81 %	100.00 %
	Normal	Arithmetic mean/s	1180.34 ± 79.54	3742.62 ± 384.38	2232.86 ± 195.71	7249.55 ± 487.07
		Median/s	1167.00	3717.00	2202.00	7156.00
		Weights	16.28 %	51.63 %	30.80 %	100.00 %
	Low Altitude	Arithmetic mean/s	1144.26 ± 69.45	3765.99 ± 391.99	2148.13 ± 219.31	7168.84 ± 571.03
		Median/s	1134.00	3664.00	2096.00	7046.50
		Weights	15.96 %	52.53 %	29.96 %	100.00 %
Women	High Altitude	Arithmetic mean/s	1232.83 ± 20.42	3932.33 ± 54.82	2422.93 ± 136.83	7655 ± 145.11
		Median/s	1233.50	3930.00	2392.50	7625.00
		Weights	16.10 %	51.37 %	31.65 %	100.00 %
	Normal	Arithmetic mean/s	1259.63 ± 36.53	4412.92 ± 479.29	2477.05 ± 238.52	8249.03 ± 627.92
		Median/s	1261.50	4271.00	2422.50	8067.00
		Weights	15.27 %	53.50 %	30.03 %	100.00 %
	Low Altitude	Arithmetic mean/s	1234.12 ± 54.36	4173.61 ± 450.91	2435.96 ± 229.95	7963.53 ± 614.98
		Median/s	1223.00	3971.00	2386.00	7807.00
		Weights	15.50 %	52.41 %	30.59 %	100.00 %

score against the total score at different altitudes, as shown in Table 6 and Fig. 2((a)-(b)). The results show that for both men and women, increasing and decreasing elevation increased the effect of swimming and running on overall performance relative to normal elevation; the effect of running on overall performance was greater than that of cycling at high elevation.

4.3. Effects of waters change on athlete performance

Through mathematical method, we obtained the arithmetic mean, median and weight of each performance for men and women in different waters (see Table 7). The results in Table 7 show that the overall performance in still waters is better than that in precipitation and seawaters.

Similarly, we calculated the PRCC of each item score against the total score for different waters, as shown in Table 8 and Fig. 3((a)-(b)). The results show that for men, cycling has the greatest effect on overall performance under different waters, followed by running. Swimming has the least effect on overall performance. For female athletes, in river waters, swimming has a greater effect on overall performance than cycling, but less than running.

5. Discussions

We studied the Triathlon sports using the results achieved by 984 athletes who participated in triathlons within China from 2015 to 2021. The study examined the sensitivity of the three splits of swimming, cycling, and running to overall triathlon performance under different temperature (low, normal, and high), altitude (low, normal, and high), and waters (sea, river, and still waters). By understanding the impact of these factors, Chinese triathletes can make informed decisions about their race strategies to improve their performance. Our findings suggest that environmental factors, such as temperature, altitude, and waters, have a significant impact on triathletes' overall performance. Specifically speaking, as the temperature decreases, athletes' performance improves slightly, with running performance improving more. This may be due to the fact that high temperatures can lead to a deterioration in overall performance, whereas suitable temperatures allow athletes to perform better overall and also have more stamina for the last event, running.

When the temperature is suitable (at low temperature, at normal temperature) and the altitude is suitable (at low altitude, at normal altitude), it is the cycling performance that has the greatest impact on the overall performance for both male and female triathletes, due to the fact that the cycling event has the longest time for this discipline compared to running and especially swimming. The greatest impact of cycling performance on overall performance indicates that with equal time reductions for swimming, cycling and running, the large time reductions to overall performance were cycling. Cycling performance is strongly dependent on

Table 6
PRCC for men's and women's events and overall results at different altitudes.

		Low Altitude	Normal	High Altitude
Men	Swimming	0.58	0.49	0.77
	Cycling	0.96	0.97	0.90
	Running	0.89	0.86	0.96
Women	Swimming	0.39	0.33	0.78
	Cycling	0.96	0.93	0.79
	Running	0.88	0.78	0.94

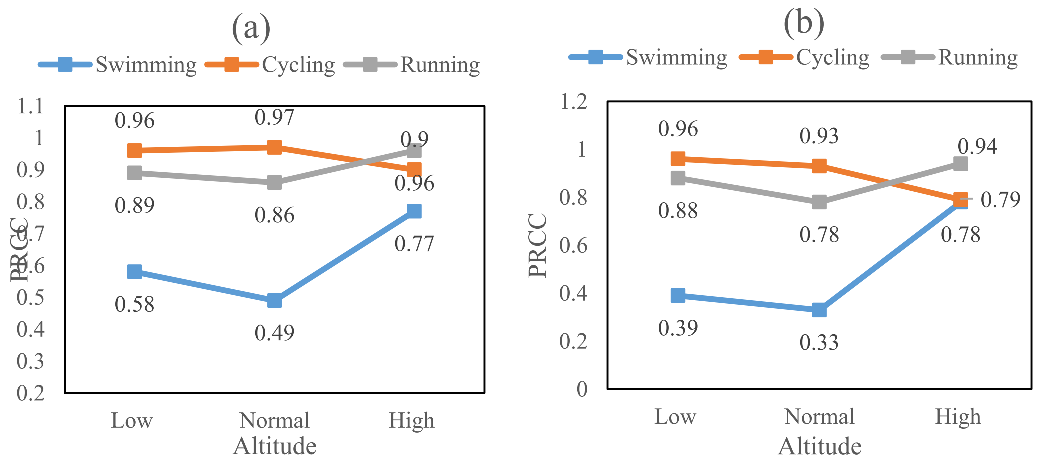

Fig. 2. The PRCC of each performance and the overall performance for men (a) and women (b) at different altitudes.

Table 7
Results of split and overall performance in different waters.

			Swimming	Cycling	Running	Overall
Men	Seawaters	Arithmetic mean/s	1134.83 ± 79.24	3943.07 ± 470.06	2113.34 ± 238.26	7313.36 ± 710.05
		Median/s	1109.00	3885.00	2055.00	7118.00
		Weights	15.52 %	53.92 %	28.90 %	100.00 %
	River waters	Arithmetic mean/s	1182.68 ± 80.35	3626.29 ± 259.09	2294.06 ± 193.97	7185.29 ± 424.7
		Median/s	1151.50	3614.00	2259.50	7155.00
		Weights	16.46 %	50.47 %	31.93 %	100.00 %
	Stillwaters	Arithmetic mean/s	1155.82 ± 55.2	3616.31 ± 242.13	2175.29 ± 185.63	7043.81 ± 375.05
		Median/s	1148.50	3582.50	2131.50	6966.50
		Weights	16.41 %	51.34 %	30.88 %	100.00 %
Women	Seawaters	Arithmetic mean/s	1246.45 ± 59.23	4418.48 ± 522.74	2399.69 ± 219.2	8193.31 ± 724.28
		Median/s	1241.00	4404.00	2338.00	8010.00
		Weights	15.21 %	53.93 %	29.29 %	100.00 %
	River waters	Arithmetic mean/s	1234.5 ± 47.3	4057.22 ± 222.5	2504.75 ± 252.06	7880.5 ± 451.49
		Median/s	1224.50	3944.00	2433.00	7694.00
		Weights	15.67 %	51.48 %	31.78 %	100.00 %
	Stillwaters	Arithmetic mean/s	1229.72 ± 44.25	4020.29 ± 317.39	2457.6 ± 220.1	7814.53 ± 463.4
		Median/s	1223.50	3930.00	2409.50	7650.00
		Weights	15.74 %	51.45 %	31.45 %	100.00 %

Table 8
PRCC for men's and women's events and overall results in different waters.

		Stillwaters	River waters	Seawaters
Men	Swimming	0.49	0.49	0.62
	Cycling	0.94	0.93	0.95
	Running	0.91	0.84	0.88
Women	Swimming	0.24	0.58	0.36
	Cycling	0.87	0.54	0.95
	Running	0.87	0.93	0.76

aerodynamic drag, of which the majority is attributable to the rider. Previous studies have shown the importance of optimizing athlete posture on the bicycle for individual time-trial events [13].

However, when at high altitude, running performance had the greatest effect on overall performance. There are studies reporting that running is the discipline that most influences the overall performance (race time) in the Olympic distance [[14–16]]. For any triathlon distance (short, Olympic, half-distance and full-distance), competitors spend more time cycling than swimming or running, but running has emerged as the discipline with the greatest influence on overall performance at the Olympic distance [17]. Running performance is a determinant factor for victory in Sprint and Olympic distance triathlon [18].

Furthermore, in most environments, the swim consistently had a smaller effect on overall performance than the cycling and running. However, when the aquatic environment was river waters, women's swimming had a greater impact on overall performance

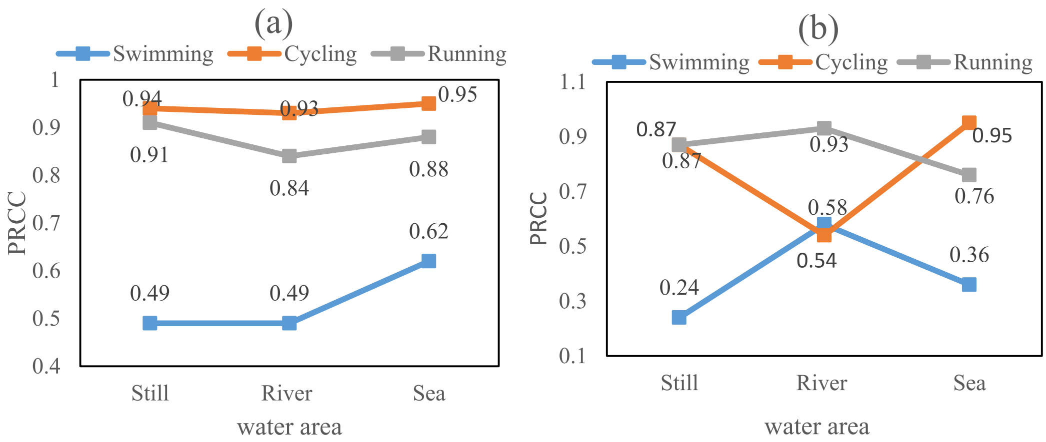

Fig. 3. The PRCC of each performance and the overall performance for men (a) and women (b) at different waters.

than cycling did. This may be due to the complexity of the river waters environment, which requires more energy from female athletes to maintain speed and cope with the environment.

Based on the above research results, we put forward the following suggestions:

(1) Cycling performance has the greatest impact on overall performance under suitable temperature and altitude conditions. Therefore, when competing in this type of environment, athletes should focus on their performance in cycling events. (2) When participating in high temperature or high-altitude triathlon competitions, athletes should strengthen their running ability and pay attention to the reasonable distribution of physical energy during the race to ensure the physical reserve during the run. (3) Before taking part in triathlon races in complicated waters, athletes need to strengthen swimming practice in a targeted way, especially female athletes should strengthen their training in river waters environment.

5.1. Limitation

One limitation of our study is that we considered only a few environmental factors, and the amount of data analyzed was relatively small. To gain a comprehensive understanding of the impact of environmental conditions on triathletes' performance, future studies could analyze internationally renowned competitions and gather data on other environmental factors, such as wind direction, wind speed, and waters temperature. An in-depth analysis of this data could provide insights into the specific impact of environmental conditions on triathletes' performance, enabling the customization of training regimens to better prepare athletes for these conditions.

6. Conclusions

This study has investigated the performance of triathletes in different environments using sensitivity analysis. Our findings demonstrate that the three split times have different effects on overall time in different environments. Specifically, in suitable environments (with low or normal temperature and low or normal altitude), cycling had the greatest impact on the overall performance. However, in high temperature and high-altitude environments, running had the greatest impact on the overall performance. These results suggest that athletes should tailor their training and race strategies to the specific environmental conditions they will face during competition.

Based on our findings, we recommend that athletes, coaches, and competition organizers take into account the impact of environmental factors when planning for races. Athletes may benefit from focusing on improving their cycling performance in suitable environments while prioritizing running performance in challenging conditions. Coaches can also adjust training programs to simulate different environments to help athletes better prepare for competition. Competition organizers may consider implementing measures to mitigate the impact of extreme environmental conditions on athlete performance.

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Ethics approval

Not applicable.

Consent

Not applicable.

Data availability statement

The results data that support the findings of this study are publicly available on the official website (http://triathlon.basts.com.cn/#home).

Authors' information

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CRediT authorship contribution statement

Junhui Zhao: Writing – review & editing, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Data curation, Conceptualization. **Yan Wu:** Writing – original draft. **Jiangqian Zhang:** Software, Formal analysis.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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