HUMAN MOVEMENT (ISSN 1899-1955)
2024; 25(2): 148–160

A study of the fastest courses for professional triathletes competing in IRONMAN® triathlons

original paper
DOI: https://doi.org/10.5114/hm/189332

MABLINY THUANY[1], DAVID VALERO[2], ELIAS VILLIGER[3], MATHEUS SANTOS SOUSA FERNANDES[4], PEDRO FORTE[5,6], KATJA WEISS[3], PANTELIS T. NIKOLAIDIS[7], IVAN CUK[8], BEAT KNECHTLE[3,9]

[1] Faculty of Sports, University of Porto, Porto, Portugal
[2] Ultra Sports Science Foundation, Pierre-Benite, France
[3] Institute of Primary Care, University of Zurich, Zurich, Switzerland
[4] Keizo Asami Institute of Immunopathology, Federal University of Pernambuco, Recife, Brazil
[5] CI-ISCE, Higher Institute of Educational Sciences of the Douro, Penafiel, Portugal
[6] Department of Sports, Instituto Politécnico de Bragança, Bragança, Portugal
[7] School of Health and Caring Sciences, University of West Attica, Athens, Greece
[8] Faculty of Sport and Physical Education, University of Belgrade, Belgrade, Serbia
[9] Medbase St. Gallen Am Vadianplatz, St. Gallen, Switzerland

ABSTRACT

Purpose. The IRONMAN® triathlon is an endurance multisport discipline of high popularity. Professional IRONMAN® triathletes need to qualify for the IRONMAN® World Championships and, therefore, would benefit from identifying the fastest race courses. Our purpose was to identify the fastest races held for professional IRONMAN® triathletes competing from 2002 to 2022.

Methods. This was an observational study, sampling 7,078 race records (380 different events in 55 different event locations) of professional IRONMAN® triathletes of both sexes (4,235 males and 2,843 females). We downloaded information about sex, nationality, both split (swimming, cycling, and running) and overall race times, the event location, and the year. Information about race course characteristics, water temperatures, and air temperatures was obtained. Descriptive statistics were calculated for each event location, and factorial ANOVA tests were used to explore the statistical significance of the results. A confidence interval of 95% was adopted.

Results. The fastest overall IRONMAN® average race times were achieved during the IRONMAN® Tallinn, IRONMAN® Switzerland held in Thun, and IRONMAN® Des Moines. A lake for the swim split characterized the first five courses, while the bike split featured rolling or hilly terrain. For the run split, most of the courses were characterized as flat. For environmental characteristics, lower water and air temperatures also added time to the average finish time.

Conclusions. Understanding the fastest race courses and their characteristics would assist professional IRONMAN® triathletes in selecting races that offer the optimal conditions for their competition. Fast IRONMAN® race courses typically feature a lakeside swim course, a rolling or hilly bike course, and a flat run course.

Key words: swimming, cycling, running, multisport, elite athlete

Introduction

Sports sciences were strongly influenced by the analytical approach, in which large quantities of information, quantitative research methods, and big data serve to study athlete performances [1]. This approach overvalues the athlete's characteristics as the most important predictors of performance, instead of considering the relationship between the subject and the environment [2]. Studies about the influence of the environment on an athlete's performance can be developed through different perspectives, considering the

Correspondence address: Beat Knechtle, Institute of Primary Care, University of Zurich, CH-8006 Zürich, Switzerland, e-mail: beat.knechtle@hispeed.ch; https://orcid.org/0000-0002-2412-9103

Received: January 07, 2024
Accepted for publication: May 27, 2024

Citation: Thuany M, Valero D, Villiger E, Fernandes MSS, Forte P, Weiss K, Nikolaidis PT, Cuk I, Knechtle B. A study of the fastest courses for professional triathletes competing in IRONMAN® triathlons. Hum Mov. 2024;25(2):148–160; doi: https://doi.org/10.5114/hm/189332.

birthplace, social environment (e.g., coach, family, and peer influence), the infrastructure and equipment available for training, and the weather characteristics, among others [3, 4].

Endurance sports have been the subject of extensive study with researchers using different theoretical and methodological approaches [2, 5]. Recently, triathlons have received increased attention since they represent one of the most challenging sports practiced worldwide [6–8]. Investigations into triathlon performance have been developed through different topics, such as nutrition [9], training [10, 11], physics [12, 13], and environmental factors in the prediction of performance [14]. For triathlons, in which the athletes are constantly exposed to constraints through the race courses, investigating the influence of environmental variables could provide valuable information for athletes, coaches, and event organizers [15–17].

From the previous literature, it has been emphasized that pacing is influenced by wind velocity, topography, and other competitors [18]. Similarly, hot and humid conditions slow triathletes and increase the rate of withdrawal in the IRONMAN® World Championships in Kona (Hawaii) [19]. However, no data is available on the role the event location has on the IRONMAN® triathletes' performance, where athletes have to cover 3.8 km swimming, 180 km cycling, and 42.195 km running. Considering the particularities of a triathlon, the role of the event location on the athlete's performance can be influenced by different characteristics, including the natural environment (e.g., altitude, temperature, and humidity) [5], the type of terrain on the bike course (e.g., hills and turns) [19], and the water temperature [20, 21].

For professional triathletes competing in IRONMAN® 70.3, a previous study showed that lower temperatures and dynamic terrain are important characteristics of some race courses, with better swimming performance achieved in geographically protected and calm waters where the course was straight with a minimum of turns [22]. Thus, choosing the best location may help athletes to improve their performance. We aimed to analyse a large data set, covering a big portion of triathlon events worldwide, to identify the fastest race courses for professional IRONMAN® triathletes competing between 2002 and 2022. With this knowledge, these professional IRONMAN® triathletes can better select a race course to achieve the fastest race time.

Material and methods

Study design, data set, and data preparation

This is an exploratory study using information obtained from the official website of IRONMAN® Triathlons (www.ironman.com). We considered all the race records from professional IRONMAN® triathletes competing between 2002 and 2022 in all IRONMAN® triathlon races held worldwide, as well as the information related to each specific location. Race record data included the triathlete's gender, nationality, overall race times, event location, and year. Location data included the type of race course for each split discipline and the average air and water temperatures on race days. After processing the data and cleaning up any invalid records, a resulting set of 7,078 professional race records (4,235 from males and 2,843 from females) from 2,354 unique triathletes from 69 different countries of origin were used for analysis. The data covers a total of 380 IRONMAN® PRO races celebrated between 2002 and 2022 throughout 55 different event locations. We did not control for the repeat participation of IRONMAN® triathletes and instead considered each sample independent.

Statistical analysis

The distributions of the full race times were checked for normality by plotting their histograms. Records were then aggregated by event location, and descriptive statistics, including mean, standard deviation, and minimum and maximum values, were calculated for each location. The statistical significance of the differences in the time between the race locations was investigated with factorial ANOVA tests. A confidence interval of 95% was adopted. We then built a regression model using the XG Boost algorithm, with the triathlete's sex and country of origin, the event location, water temperature, and air temperature as predicting variables and the finish time as the predicted variable. The model-agnostic SHAP library was used to investigate how each of the predictors influenced the model output. All statistical analyses were performed with Python 3 (www.python.org/) in a Google Colab notebook (https://colab.google/), both freely available.

Results

The dataset consisted of 7,078 race records of professional IRONMAN® triathletes competing in 380 different events in 55 different event locations. Table 1

Table 1. Details of the IRONMAN® PRO race locations between 2002 and 2022

	Event location	Number of races	Number of records	Number of unique athletes
1	IRONMAN® Hawaii	18	928	523
2	IRONMAN® Florida	15	570	435
3	IRONMAN® Austria	16	466	338
4	IRONMAN® France	15	357	250
5	IRONMAN® Wisconsin	18	330	252
6	IRONMAN® Lanzarote	11	323	235
7	IRONMAN® Texas	10	314	238
8	IRONMAN® Arizona	16	260	205
9	IRONMAN® Lake Placid	17	246	192
10	IRONMAN® South Africa	7	198	153
11	IRONMAN® Brazil Florianopolis	10	196	149
12	IRONMAN® Barcelona	5	195	165
13	IRONMAN® Louisville	8	180	131
14	IRONMAN® Cozumel	12	166	142
15	IRONMAN® Mallorca	4	159	146
16	IRONMAN® New Zealand	17	152	129
17	IRONMAN® Zurich Switzerland	8	128	110
18	IRONMAN® Frankfurt	12	127	104
19	IRONMAN® Western Australia	10	125	104
20	IRONMAN® Canada	14	122	109
21	IRONMAN® Chattanooga	6	116	95
22	IRONMAN® Wales	8	112	91
23	IRONMAN® Copenhagen	8	102	92
24	IRONMAN® Emilia Romagna	3	95	85
25	IRONMAN® Mont-Tremblant	8	92	76
26	IRONMAN® Malaysia	7	91	66
27	IRONMAN® UK	10	88	70
28	IRONMAN® Coeur d'Alene	12	81	78
29	IRONMAN® Cairns	11	75	66
30	IRONMAN® Boulder	4	69	56
31	IRONMAN® Hamburg	4	59	54
32	IRONMAN® Maastricht	4	55	48
33	IRONMAN® Taiwan	3	51	43
34	IRONMAN® Australia, New South Wales	11	50	45
35	IRONMAN® Kalmar	8	41	35
36	IRONMAN® Japan	3	38	33
37	IRONMAN® Regensburg	2	29	27
38	IRONMAN® Melbourne	3	29	29
39	IRONMAN® Vichy	1	28	28
40	IRONMAN® Tulsa	1	27	27
41	IRONMAN® China	2	26	25
42	IRONMAN® St. George	3	21	20
43	IRONMAN® Des Moines	1	21	21
44	IRONMAN® Los Cabos	2	20	20
45	IRONMAN® Subic Bay Philippines	1	19	19
46	IRONMAN® Lake Tahoe	1	18	18
47	IRONMAN® Vitoria-Gasteiz	1	16	16
48	IRONMAN® Vineman	1	16	16
49	IRONMAN® Tallinn	2	11	11
50	IRONMAN® Mar del Plata	1	10	10
51	IRONMAN® New York	1	10	10
52	IRONMAN® Switzerland Thun	1	7	7
53	IRONMAN® Finland Kuopio-Tahko	1	7	7
54	IRONMAN® Brazil Fortaleza	1	5	5
55	IRONMAN® Maryland	1	1	1

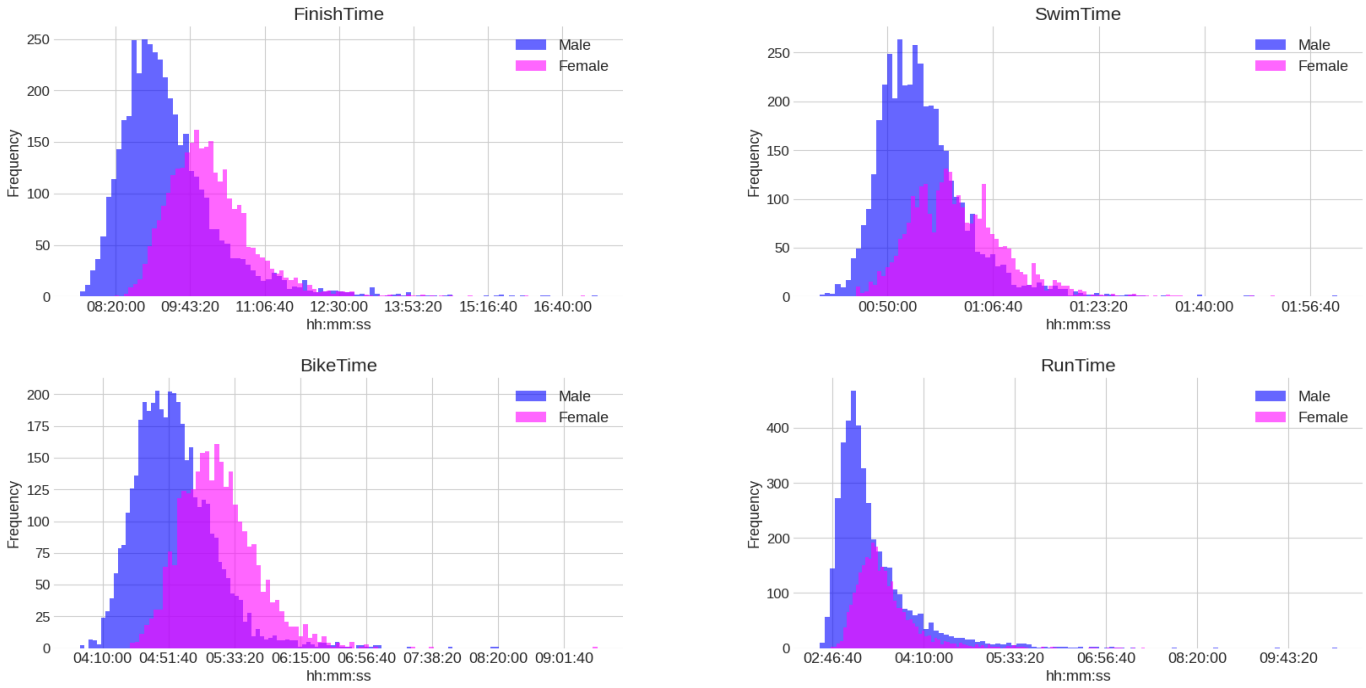

Figure 1. Histograms of IRONMAN® professionals overall and split times between 2002 and 2022

Table 2. Data tables of the 20 fastest IRONMAN race courses based on overall race times

	Event location	Count	Mean	*SD*	Max	Min	Swim	Bike	Run	Water (°C)	Air (°C)
1	IRONMAN® Tallinn	11	09:00:30	00:40:13	10:46:58	08:13:33	lake	rolling	flat	18	17
2	IRONMAN® Switzerland Thun	7	09:01:10	00:22:43	09:32:02	08:34:18	lake	hilly	flat	17	20
3	IRONMAN® Des Moines	21	09:03:51	00:47:53	10:38:50	07:56:48	lake	rolling	flat	22	22
4	IRONMAN® Barcelona	195	09:04:40	00:44:07	11:56:04	07:49:19	lake	hilly	rolling	23	21
5	IRONMAN® Vichy	28	09:05:18	00:34:48	10:18:12	08:17:14	lake	hilly	flat	25	28
6	IRONMAN® Vitoria-Gasteiz	16	09:06:28	00:40:57	10:55:26	08:08:02	lake	rolling	flat	21	22
7	IRONMAN® Emilia Romagna	95	09:09:55	00:44:49	11:53:51	07:46:54	ocean	flat	flat	22	25
8	IRONMAN® Texas	314	09:09:56	00:48:47	13:07:28	07:39:57	lake	flat	rolling	28	23
9	IRONMAN® Copenhagen	102	09:12:41	00:51:15	12:57:41	07:46:06	bay	rolling	flat	18	21
10	IRONMAN® Western Australia	125	09:14:08	00:50:01	12:20:42	07:45:20	bay	flat	flat	20	27
11	IRONMAN® Mallorca	159	09:17:52	00:42:20	11:43:01	07:57:59	ocean	hilly	flat	17	25
12	IRONMAN® Tulsa	27	09:19:11	01:09:41	13:12:22	07:45:22	lake	rolling	flat	23	23
13	IRONMAN® New York	10	09:19:57	00:36:36	10:03:14	08:29:20	bay	flat	flat	18	21
14	IRONMAN® Austria	466	09:20:46	00:52:58	15:59:24	07:51:09	lake	rolling	flat	23	27
15	IRONMAN® Hamburg	59	09:21:14	00:48:45	12:38:35	08:00:36	lake	flat	rolling	21	23
16	IRONMAN® Brazil Fortaleza	5	09:24:30	00:30:41	10:11:36	08:52:54	ocean	flat	flat	28	31
17	IRONMAN® Finland Kuopio-Tahko	7	09:24:33	00:21:33	10:00:03	08:59:26	lake	rolling	rolling	18	18
18	IRONMAN® Cairns	75	09:25:00	00:49:45	12:05:47	07:52:54	ocean	rolling	flat	23	26
19	IRONMAN® Chattanooga	116	09:27:12	00:42:41	11:32:08	08:08:32	river	rolling	rolling	25	24
20	IRONMAN® Brazil Florianopolis	196	09:28:35	00:55:58	13:09:49	07:53:11	ocean	flat	flat	20	21

Table 3. Data tables of the 20 fastest IRONMAN race courses based on swimming split times

	Event location	Count	Mean	*SD*	Max	Min	Swim	Bike	Run	Water (°C)	Air (°C)
1	IRONMAN® New York	10	00:45:41	00:01:52	00:47:53	00:42:40	bay	flat	flat	18	21
2	IRONMAN® Switzerland Thun	7	00:48:30	00:06:48	00:59:33	00:42:20	lake	hilly	flat	17	20
3	IRONMAN® Chattanooga	116	00:48:47	00:04:18	00:59:43	00:40:39	river	rolling	rolling	25	24
4	IRONMAN® Cozumel	166	00:51:45	00:07:44	01:22:32	00:39:18	ocean	flat	flat	26	26
5	IRONMAN® Regensburg	29	00:54:39	00:05:48	01:08:01	00:46:51	lake	rolling	flat	22	26
6	IRONMAN® Emilia Romagna	95	00:54:45	00:07:13	01:20:47	00:44:30	ocean	flat	flat	22	25
7	IRONMAN® Brazil Florianopolis	196	00:55:12	00:08:32	01:25:42	00:42:27	ocean	flat	flat	20	21
8	IRONMAN® New Zealand	152	00:55:32	00:06:18	01:13:10	00:44:47	lake	rolling	flat	18	21
9	IRONMAN® Mallorca	159	00:55:35	00:05:56	01:19:47	00:44:46	ocean	hilly	flat	17	25
10	IRONMAN® Cairns	75	00:55:36	00:07:49	01:13:46	00:43:29	ocean	rolling	flat	23	26
11	IRONMAN® China	26	00:55:37	00:09:52	01:29:58	00:40:04	ocean	flat	flat	24	32
12	IRONMAN® Western Australia	125	00:55:39	00:06:24	01:19:08	00:46:22	bay	flat	flat	20	27
13	IRONMAN® Australia – New South Wales	50	00:55:47	00:06:17	01:09:52	00:44:44	river	rolling	flat	23	21
14	IRONMAN® Brazil Fortaleza	5	00:56:07	00:03:58	01:01:10	00:51:58	ocean	flat	flat	28	31
15	IRONMAN® Austria	466	00:56:16	00:07:24	01:25:50	00:42:54	lake	rolling	flat	23	27
16	IRONMAN® Lanzarote	323	00:56:20	00:06:06	01:30:24	00:46:31	ocean	hilly	rolling	19	24
17	IRONMAN® Barcelona	195	00:56:27	00:08:10	01:28:06	00:45:34	lake	hilly	rolling	23	21
18	IRONMAN® Copenhagen	102	00:56:30	00:06:55	01:29:00	00:45:54	bay	rolling	flat	18	21
19	IRONMAN® Des Moines	21	00:56:31	00:05:48	01:10:40	00:48:54	lake	rolling	flat	22	22
20	IRONMAN® Maastricht	55	00:56:32	00:09:53	01:28:56	00:46:19	river	rolling	flat	20	27

Table 4. Data tables of the 20 fastest IRONMAN race courses based on cycling split times

	Event location	Count	Mean	*SD*	Max	Min	Swim	Bike	Run	Water (°C)	Air (°C)
1	IRONMAN® Des Moines	21	04:38:43	00:20:14	05:16:31	04:09:58	lake	rolling	flat	22	22
2	IRONMAN® Barcelona	195	04:41:54	00:16:40	05:49:46	04:09:55	lake	hilly	rolling	23	21
3	IRONMAN® Tallinn	11	04:42:19	00:14:12	05:11:24	04:26:20	lake	rolling	flat	18	17
4	IRONMAN® Texas	314	04:44:34	00:21:51	05:48:25	03:55:45	lake	flat	rolling	28	23
5	IRONMAN® Vichy	28	04:46:12	00:17:42	05:24:07	04:22:29	lake	hilly	flat	25	28
6	IRONMAN® Emilia Romagna	95	04:48:38	00:19:19	05:53:24	04:09:03	ocean	flat	flat	22	25
7	IRONMAN® Copenhagen	102	04:48:49	00:22:35	05:51:00	04:02:19	bay	rolling	flat	18	21
8	IRONMAN® Western Australia	125	04:49:29	00:21:54	06:18:50	04:08:12	bay	flat	flat	20	27
9	IRONMAN® Vitoria-Gasteiz	16	04:49:46	00:20:10	05:48:24	04:27:27	lake	rolling	flat	21	22
10	IRONMAN® Boulder	69	04:51:26	00:21:32	05:42:19	04:13:26	reservoir	hilly	hilly	17	26
11	IRONMAN® Brazil Fortaleza	5	04:53:39	00:10:22	05:08:43	04:40:32	ocean	flat	flat	28	31
12	IRONMAN® Hamburg	59	04:55:39	00:21:25	06:12:29	04:17:29	lake	flat	rolling	21	23
13	IRONMAN® Florida	570	04:56:18	00:23:55	06:31:19	04:01:50	ocean	flat	flat	22	19
14	IRONMAN® Austria	466	04:56:27	00:21:32	07:26:46	04:09:30	lake	rolling	flat	23	27
15	IRONMAN® Switzerland Thun	7	04:58:12	00:09:40	05:10:04	04:45:35	lake	hilly	flat	17	20
16	IRONMAN® Mallorca	159	04:59:02	00:19:38	06:05:51	04:16:41	ocean	hilly	flat	17	25
17	IRONMAN® Tulsa	27	04:59:37	00:30:37	06:08:37	04:17:07	lake	rolling	flat	23	23
18	IRONMAN® Cozumel	166	04:59:59	00:28:41	06:37:56	04:15:30	ocean	flat	flat	26	26
19	IRONMAN® Melbourne	29	05:00:02	00:22:49	05:48:15	04:20:50	bay	flat	flat	17	18
20	IRONMAN® Brazil Florianopolis	196	05:00:11	00:24:02	06:18:14	04:11:03	ocean	flat	flat	20	21

Table 5. Data tables of the 20 fastest IRONMANR race courses based on running split times

	Event location	Count	Mean	*SD*	Max	Min	Swim	Bike	Run	Water (°C)	Air (°C)
1	IRONMAN® Switzerland Thun	7	03:09:13	00:10:22	03:28:21	02:54:27	lake	hilly	flat	17	20
2	IRONMAN® Vichy	28	03:12:30	00:21:48	04:32:55	02:45:37	lake	hilly	flat	25	28
3	IRONMAN® Vitoria-Gasteiz	16	03:14:01	00:21:55	04:06:42	02:47:45	lake	rolling	flat	21	22
4	IRONMAN® Tallinn	11	03:14:35	00:21:43	04:10:12	02:49:02	lake	rolling	flat	18	17
5	IRONMAN® Tulsa	27	03:16:17	00:33:00	04:59:18	02:36:03	lake	rolling	flat	23	23
6	IRONMAN® Mallorca	159	03:17:08	00:23:52	05:25:32	02:42:11	ocean	hilly	flat	17	25
7	IRONMAN® Hamburg	59	03:17:11	00:24:09	05:01:59	02:40:58	lake	flat	rolling	21	23
8	IRONMAN® Lanzarote	323	03:18:00	00:28:15	06:57:36	02:40:37	ocean	hilly	rolling	19	24
9	IRONMAN® Emilia Romagna	95	03:18:17	00:25:12	05:06:13	02:45:02	ocean	flat	flat	22	25
10	IRONMAN® Finland Kuopio-Tahko	7	03:18:48	00:06:54	03:31:38	03:10:24	lake	rolling	rolling	18	18
11	IRONMAN® UK	88	03:19:18	00:24:04	04:56:55	02:43:21	river	hilly	rolling	18	22
12	IRONMAN® Des Moines	21	03:20:09	00:31:20	04:54:38	02:47:22	lake	rolling	flat	22	22
13	IRONMAN® Barcelona	195	03:20:34	00:26:19	05:19:42	02:41:25	lake	hilly	rolling	23	21
14	IRONMAN® France	357	03:20:45	00:29:48	06:35:28	02:37:01	ocean	hilly	flat	24	28
15	IRONMAN® Copenhagen	102	03:21:29	00:28:26	06:14:39	02:45:10	bay	rolling	flat	18	21
16	IRONMAN® Austria	466	03:21:40	00:31:30	06:45:07	02:35:19	lake	rolling	flat	23	27
17	IRONMAN® Texas	314	03:21:45	00:31:30	07:06:27	02:35:19	lake	flat	rolling	28	23
18	IRONMAN® South Africa	198	03:21:52	00:29:54	06:42:00	02:43:43	bay	rolling	rolling	20	23
19	IRONMAN® Cairns	75	03:22:51	00:25:33	04:39:42	02:41:13	ocean	rolling	flat	23	26
20	IRONMAN® Hawaii	928	03:23:20	00:27:10	06:06:34	02:41:31	ocean	rolling	rolling	24	27

describes these 55 IRONMAN® race locations for professional athletes along with the number of races, the number of records, and the unique IRONMAN® triathletes in each of them. The table is sorted by number of records. Figure 1 presents the histograms for the professional IRONMAN® triathletes competing between 2002 and 2022, exhibiting a normal distribution in shapes and similar variances.

Tables 2–5 and Figures 2–5 present the 20 fastest IRONMAN® race courses based on overall race times and split times, as well as descriptive information for water temperature, air temperature, and basic characteristics of swimming, cycling, and running courses. Based on the average finish times, it was possible to verify that the fastest overall IRONMAN® race times were achieved during the IRONMAN® Tallinn (09:00:30 ± 00:40:13 h:min:s), followed by the IRONMAN® Switzerland held in Thun (09:01:10 ± 00:22:43 h:min:s), and the IRONMAN® Des Moines (09:03:51 ± 00:47:53 h:min:s, Table 2). The descriptive information showed that for swimming, the first five courses were mainly in a lake (Table 3), while for cycling, it was on rolling or hilly courses (Table 4). For running, most of the courses were characterized as flat (Table 5). The fastest swim courses were found in IRONMAN® New York, IRONMAN® Switzerland (Thun), and IRONMAN® Chattanooga (Figure 3). The fastest cycling courses were in IRONMAN® Des Moines, IRONMAN® Barcelona, and IRONMAN® Tallinn (Figure 4). And the fastest running courses were found in IRONMAN® Switzerland (Thun), IRONMAN® Vichy, and IRONMAN® Vitoria-Gasteiz (Figure 5).

For cycling, there exist statistically significant differences in the cycling performance between sex groups and (almost) the event locations and race course types (p = 0.0572), as well as their combined effect. All cycling course types are represented in the top positions, including rolling, hilly, and flat.

Figure 6 presents the results of the relative feature importance for the variables included in the predictive analysis. Interestingly, the country of origin had a higher impact than the event location. Based on the results, it was possible to verify that sex is the most important variable that influences finish time, with women (blue dots) adding between 2000 and 3000 s to the men's times (Figure 7). Low water temperature values resulted in longer full race finish times, similar to the temperatures in which the warmest temperatures shortened race finish times. For the event location and country, the findings showed that the highest IDs (corresponding to the smallest samples) seemed to give extremely positive or negative outputs.

Specifically for the interaction between event location, water, and air temperature, Figure 8 shows that for both variables, event locations with a higher number of records presented water temperatures between

Figure 2. The 20 fastest IRONMAN® race courses based on overall race times

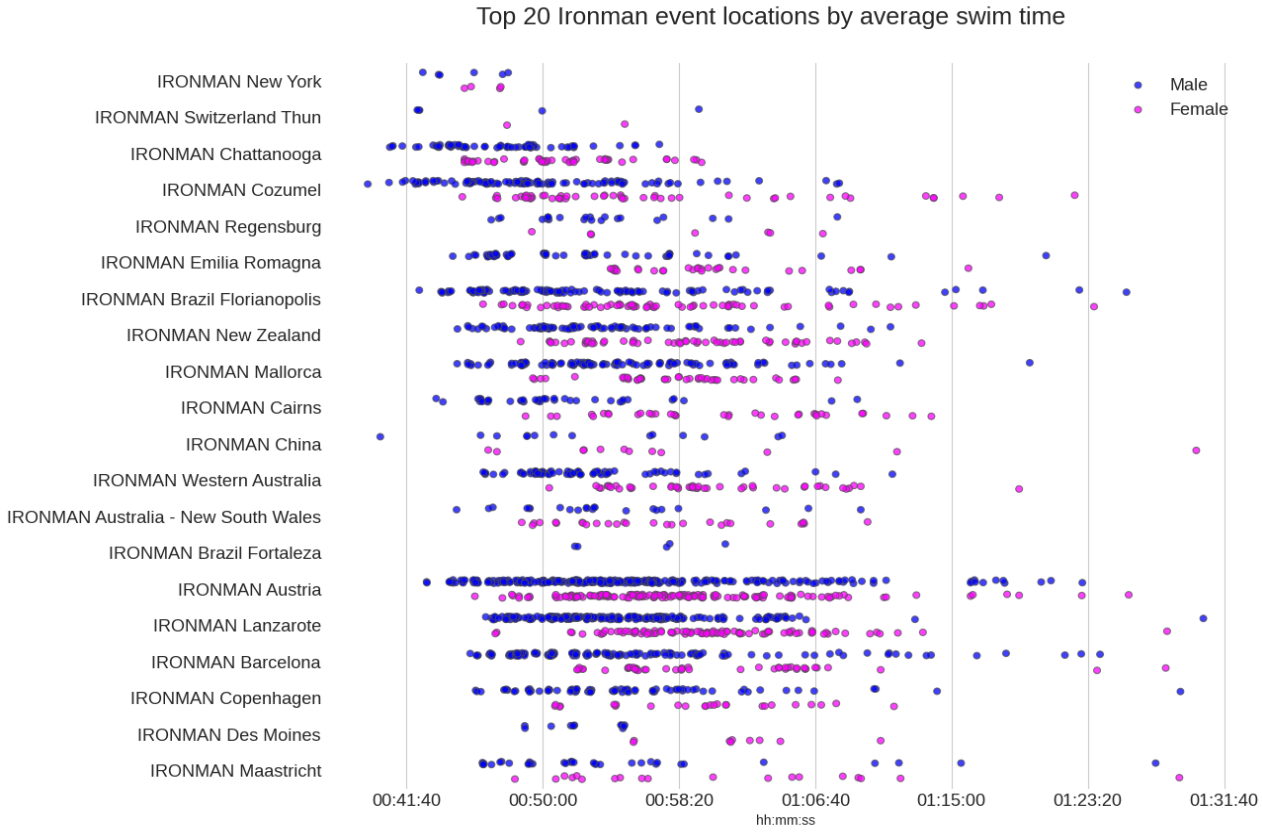

Figure 3. The 20 fastest IRONMAN® race courses based on swimming split times

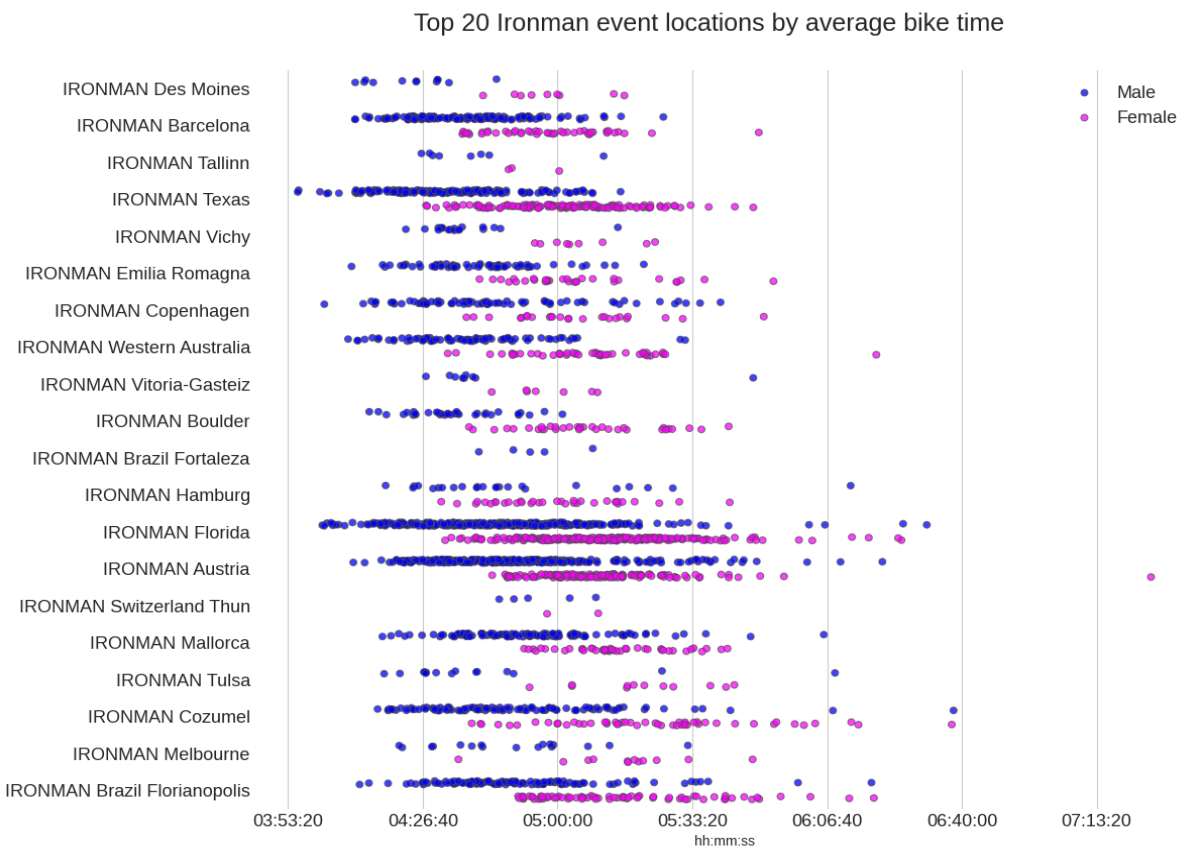

Figure 4. The 20 fastest IRONMAN® race courses based on cycling split times

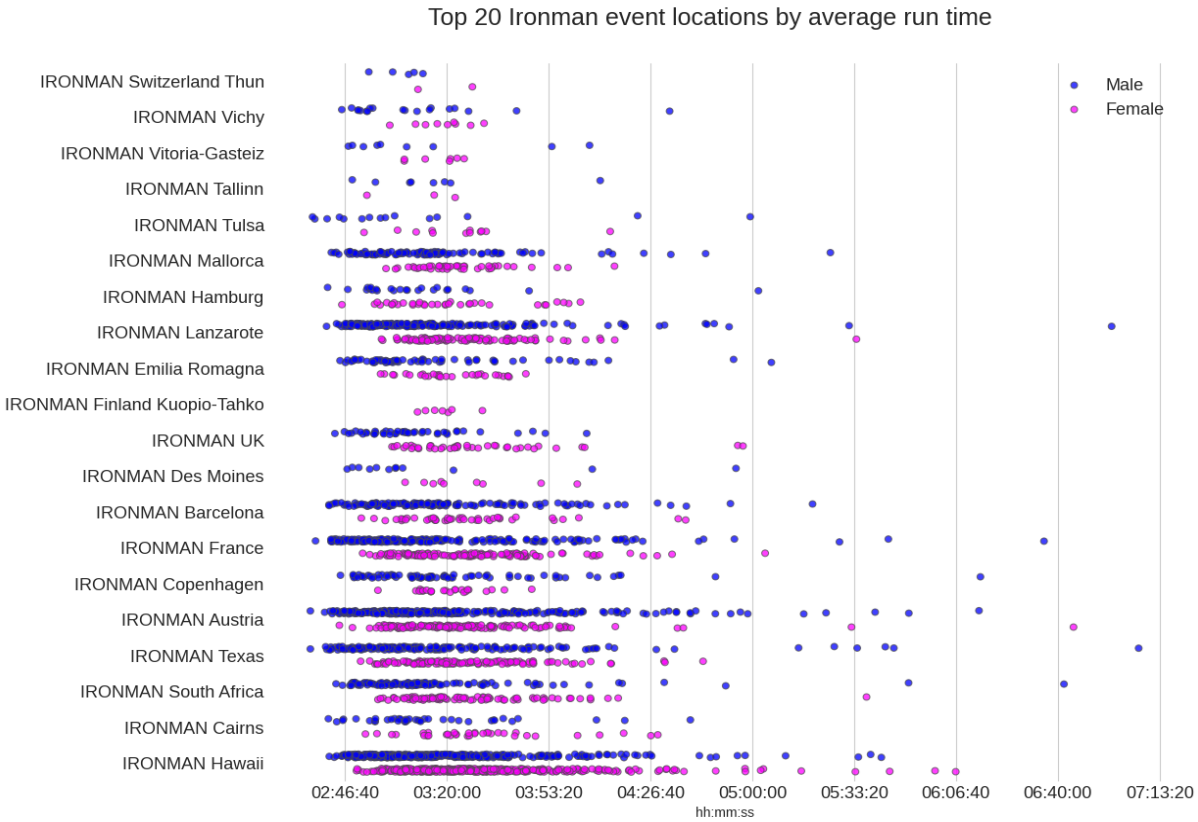

Figure 5. The 20 fastest IRONMAN® race courses

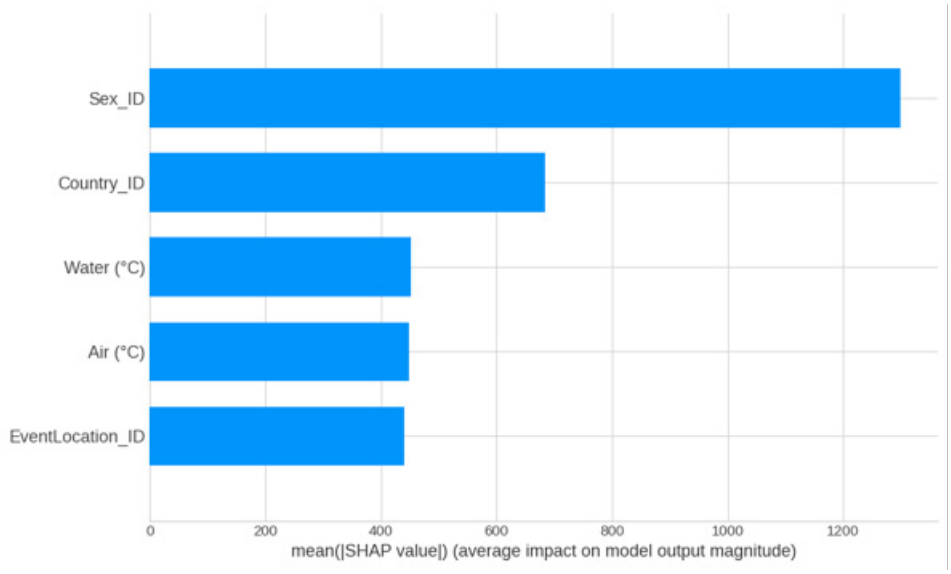

Figure 6. SHAP values and their impact on overall race times

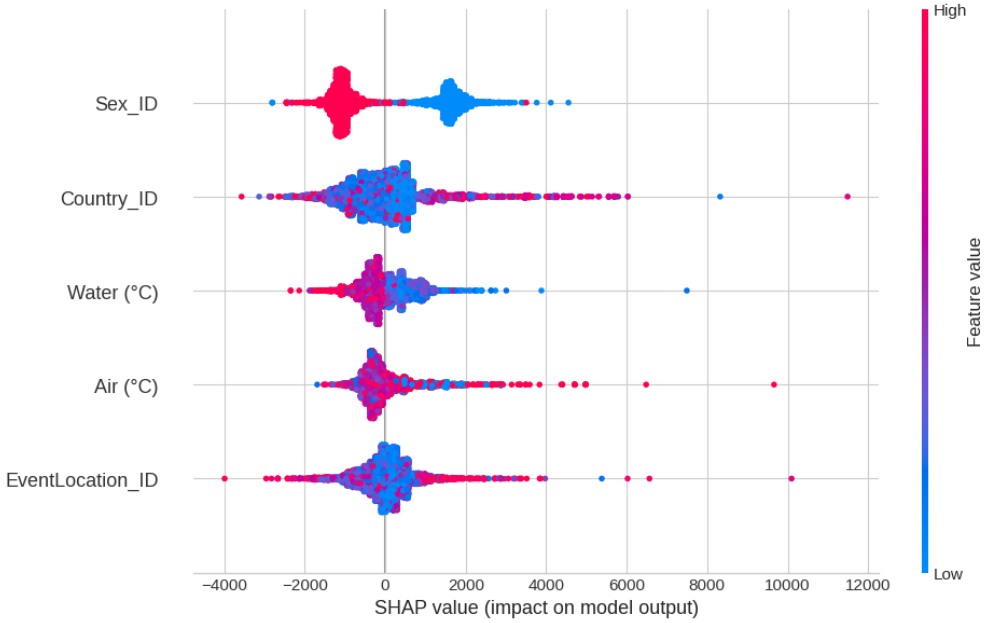

Figure 7. SHAP values of sex, country, water temperature, air temperature, and event location

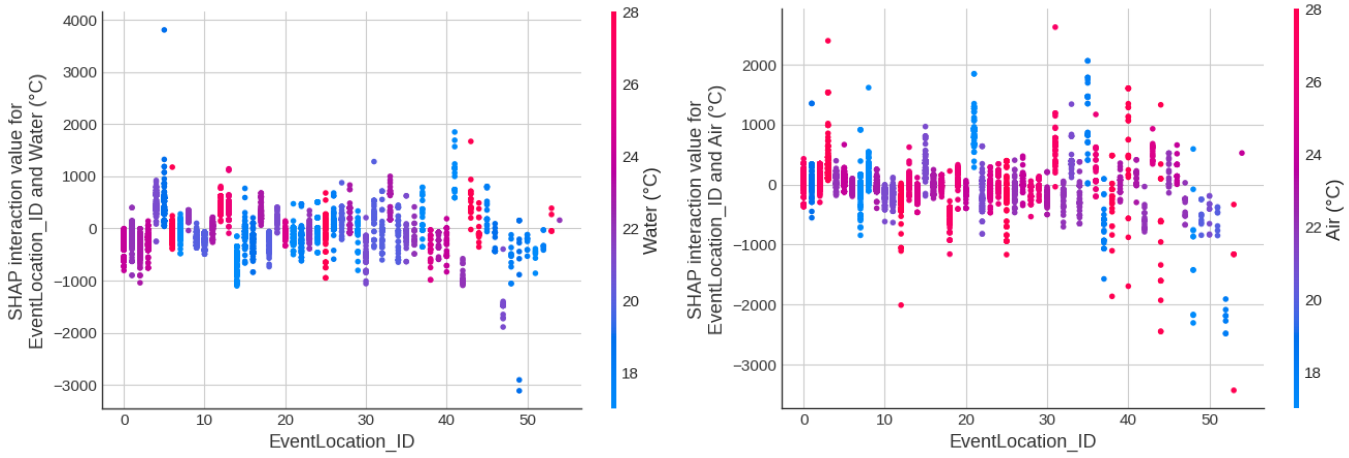

Figure 8. SHAP interaction values for the event location in association with water and air temperatures

18 and 24°C, with those between 18 and 20°C subtracting about 1000 to 3000 s off the finish time. For the air temperature, it was shown that countries with a higher number of records showed a lower air temperature compared to those with fewer records.

Discussion

This study was intended to determine the fastest overall IRONMAN® race locations for professional athletes competing from 2002 to 2022. Our main findings showed that IRONMAN® Tallinn was the fastest; the descriptive data revealed that most of the fastest finish times were found in courses characterized by swimming in a lake, cycling on a rolling course, and running on a flat course. Sex was the most important variable influencing finish times, low water temperatures impaired performance, and warmer temperatures increased race finish times. It is important to mention that studies evaluating the race courses in IRONMAN® competitions are scarce in the scientific literature, which can be associated with a greater interest in understanding the individual factors related to the performance of athletes. However, as environmental conditions influence endurance performance [5, 14, 23], it is important to advance knowledge on this topic.

The first important finding was that the fastest race course is IRONMAN® Tallinn in Estonia. Despite the lack of evidence in the scientific literature to understand these results, it is important to adopt a critical and reflexive approach. The IRONMAN® Tallinn is relatively new, with a total of two editions and 11 finishers. It can be considered an important bias in our analysis since we did not consider a minimum number of records or editions for inclusion. However, based on the descriptive information about the race courses, it was shown that in Tallinn, the swim course is one loop in Lake Harku, the cycling course is rolling, and the running course is flat [24]. The benefits of swimming in a lake can be explained by the possible lower drag due to the lake's calm water. The water waves and currents change the fluid flow and increase wave drag. Moreover, calm waters tend to have higher temperatures [25]. Finally, the lower the water temperatures, the higher the drag on swimmers [26]. For these reasons, competing in lakes seems beneficial for IRONMAN® athletes.

Regarding the cycling course, it was shown that a rolling course can be related to better performance since it favours athletes cycling in pelotons. This increases motivation given the adversary's presence and helps to spend less energy and sustain higher speed during the race [27]. Despite no studies being developed to understand the influence of the race course and the triathletes' performance in detail, previous findings reported a negative effect of uphill courses, including increasing risks of falls and injuries as a result of fatigue and a higher metabolic energy supply rate [28].

Another important aspect of the results is the environmental temperature, more precisely, water and air temperature. It was shown that event locations with a higher number of records seem to present water temperatures between 18 to 24°C, with those between 18 and 20°C subtracting about 1000 to 3000 s off the finish time. Considering air temperature, it was shown that events with a higher number of records also showed a lower air temperature compared to those with fewer records. Previous studies showed that the minimum ideal water temperature for triathletes should be 12°C in wetsuits and 16°C without wetsuits [29]. For example, the fastest race course (i.e., IRONMAN® Tallinn in Estonia) showed the lowest air temperature and presented a water temperature of 18°C. Despite this, we see that the actual water temperatures in IRONMAN® competitions are always above those levels, reaching, in some cases, up to the high 20s. As mentioned above, higher water temperatures are associated with less drag [26]. The same is observed for on-land (cycling and running) races [30]. This is because the higher the temperatures, the lower the drag. These findings highlight the role of both topographic characteristics and environmental conditions for endurance activities.

Another important result was the influence of sex. It highlights that women and men presented different performances across these courses. It is well documented that sex performance differences range from 12% to 18%, depending on the distance and individual characteristics [31]. Usually, these differences are explained by morphological and physiological differences. For example, elite female athletes present a higher body fat compared to men, which could help during swimming but penalizes a woman's performance during cycling and running [32]. For the physiological profile, women tend to present lower VO_2max results compared to men and show a higher difference in aerobic capacity between cycling and running tests. These results indicate the importance of adopting specific approaches to training, but also understanding the specificities of the race course on the performance of men and women.

Although this study used a large set of data from professional IRONMAN® triathletes competing during two decades in all IRONMAN® races held world-

wide, some limitations should be acknowledged. We did not control for multiple participations and the differences in the frequency of athletes competing in different courses over time. Also, there is a lack of data about training, nutrition, equipment, and previous experience, which could influence the preparation, race strategy, and, consequently, performance. Similarly, we do not have information about the age of peak performance of the athletes, which could influence the performance across the different seasons of the year. Another important limitation is the information about the precise temperatures is an approximation based on the mean values obtained for each event location over time. On the other hand, the strength of the present research was the novel information it provided and the potential practical applications for IRONMAN® triathletes. Since these races are held all over the world, participation infers a large demand in terms of financial cost, time, traveling-related fatigue, and sleep disturbances. Therefore, the practical information about the fastest races would be expected to aid triathletes in making optimal decisions about competing in races with favourable courses. Furthermore, the knowledge of the fastest split times would help triathletes compete in races with optimal characteristics for a specific split. These results might also help race organizers create faster races to attract more participants.

Conclusions

Based on this descriptive approach, the fastest race courses for triathletes competing between 2002 and 2022 were the IRONMAN® Tallinn, followed by the IRONMAN® Switzerland Thun and the IRONMAN® Des Moines. Most of the fastest finish times were found in courses with swimming taking place in a lake, cycling on a rolling course, and running on a flat course, with lower water temperatures impairing performance, similar to the warmest air temperatures.

Availability of data and materials

For this study, we have included official results and split times from the official website (www.ironman.com). The datasets used and/or analysed during the current study are available from the corresponding author upon reasonable request.

Ethical approval

This study was approved by the Institutional Review Board of Kanton St. Gallen, Switzerland, with a waiver of the requirement for informed consent of the participants as the study involved the analysis of publicly available data (EKSG 01/06/2010). The study was conducted following recognized ethical standards according to the Declaration of Helsinki adopted in 1964 and revised in 2013.

Disclosure statement

No author has any financial interest or received any financial benefit from this research.

Conflict of interest

The authors state no conflict of interest.

Funding

This research received no external funding.

References

[1] Loland S. Sport sciences and ECSS: approaches and challenges. Apunts Educ Fis Deportes. 2013; (111):7–14.
[2] Renfree A, Casado A. Athletic races represent complex systems, and pacing behavior should be viewed as an emergent phenomenon. Front Physiol. 2018;9; doi: 10.3389/fphys.2018.01432.
[3] Rees T, Hardy L, Gullich A, Abernethy B, Cote J, Woodman T, Montgomery H, Laing S, Warr C. The Great British medalists project: a review of current knowledge on the development of the World's Best Sporting Talent. Sports Med. 2016;46(8): 1041–58; doi: 10.1007/s40279-016-0476-2.
[4] Cote J, Macdonald D, Baker J, Abernethy B. When "where" is more important than "when": birthplace and birthdate effects on the achievement of sporting expertise. J Sports Sci. 2006;24(10): 1065–73; doi: 10.1080/02640410500432490.
[5] Thuany M, Valero D, Villiger E, Forte P, Weiss K, Nikolaidis PT, Andrade MS, Cuk I, Sousa CV, Knechtle B. A machine learning approach to finding the fastest race course for professional athletes competing in Ironman(®) 70.3 races between 2004 and 2020. Int J Environ Res Public Health. 2023;20(4); doi: 10.3390/ijerph20043619.
[6] Cushman DM, Dowling N, Ehn M, Kotler DH. Triathlon considerations. Phys Med Rehabil Clin N Am. 2022;33(1):81–90; doi: 10.1016/j.pmr.2021.08.006.
[7] Gadelha AB, Sousa CV, Sales MM, Dos Santos Rosa T, Flothmann M, Barbosa LP, da Silva Aguiar S, Olher RR, Villiger E, Nikolaidis PT, Rosemann T, Hill L, Knechtle B. Cut-off values in the prediction of success in Olympic distance triathlon. Int J Environ Res Public Health. 2020;17(24); doi: 10.3390/ijerph17249491.

[8] Barbosa LP, Sousa CV, Sales MM, Olher RDR, Aguiar SS, Santos PA, Tiozzo E, Simões HG, Nikolaidis PT, Knechtle B. Celebrating 40 years of Ironman: how the champions perform. Int J Environ Res Public Health. 2019;16(6); doi: 10.3390/ijerph16061019.
[9] Jeukendrup AE, Jentjens RL, Moseley L. Nutritional considerations in triathlon. Sports Med. 2005; 35(2):163–81; doi: 10.2165/00007256-200535020-00005.
[10] Sinisgalli R, de Lira CAB, Vancini RL, Puccinelli PJG, Hill L, Knechtle B, Nikolaidis PT, Andrade MS. Impact of training volume and experience on amateur Ironman triathlon performance. Physiol Behav. 2021;232:113344; doi: 10.1016/j.physbeh.2021.113344.
[11] Etxebarria N, Mujika I, Pyne DB. Training and competition readiness in triathlon. Sports. 2019; 7(5); doi: 10.3390/sports7050101.
[12] Czernia D, Szyk B. Air Density Calculator. 2022. Available from https://www.omnicalculator.com/physics/air-density (accessed June 22, 2024).
[13] Candau RB, Grappe F, Ménard M, Barbier B, Millet GY, Hoffman MD, Belli AR, Rouillon JD. Simplified deceleration method for assessment of resistive forces in cycling. Med Sci Sports Exerc. 1999;31(10):1441–7; doi: 10.1097/00005768-199910000-00013.
[14] Hermand E, Chabert C, Hue O. Ultra-endurance events in tropical environments and countermeasures to optimize performances and health. Int J Hyperthermia. 2019;36(1):753–60; doi: 10.1080/02656736.2019.1635718.
[15] Henriksen K, Stambulova N. The social environment of talent development in youth sport. Front Sports Act Living. 2023;5:1127151; doi: 10.3389/fspor.2023.1127151.
[16] Turner AN, Bishop C, Cree J, Carr P, McCann A, Bartholomew B, Halsted L. Building a high-performance model for sport: a human development-centered approach. Strength Cond J. 2019;41(2): 100–7; doi: 10.1519/ssc.0000000000000447.
[17] Magnusson D, Stattin H. The Person in Context. A Holistic-Interactionistic Approach. In: Damon W, Lerner R (eds) Handbook of Child Psychology. 6th ed. Hoboken: Wiley and Sons; 2006, 400–464.
[18] Wu SS, Peiffer JJ, Brisswalter J, Nosaka K, Abbiss CR. Factors influencing pacing in triathlon. Open Access J Sports Med. 2014;5:223–34; doi: 10.2147/oajsm.S44392.
[19] Stiefel M, Knechtle B, Rüst C, Rosemann T. Analysis of performances at the 'Ironman Hawaii triathlon' and its qualifier events with respect to nationality. J Sci Cycling. 2023;2(2):27–34.
[20] Strzała M, Krężałek P, Kaca M, Głąb G, Ostrowski A, Stanula A, Tyka A. Swimming speed of the breaststroke kick. J Hum Kinet. 2012;35:133–9; doi: 10.2478/v10078-012-0087-4.
[21] Gay A, Zacca R, Abraldes JA, Morales-Ortíz E, López-Contreras G, Fernandes RJ, Arellano R. Swimming with swimsuit and wetsuit at typical vs. cold-water temperatures (26 vs. 18°C). Int J Sports Med. 2021;42(14):1305–12; doi: 10.1055/a-1481-8473.
[22] Thuany M, Valero D, Villiger E, Andrade M, Weiss K, Nikolaidis P, Cuk I, Knechtle B. Where are the world's fastest Ironman ® 70.3 race courses for professional athletes? J Sci Cycling. 2023; 12(1):35–47; doi: 10.28985/1223.jsc.05.
[23] Nikolaidis PT, Di Gangi S, Chtourou H, Rüst CA, Rosemann T, Knechtle B. The role of environmental conditions on marathon running performance in men competing in Boston marathon from 1897 to 2018. Int J Environ Res Public Health. 2019; 16(4); doi: 10.3390/ijerph16040614.
[24] PJAMM Cycling. Ironman Stonia – Tallinn 2023. Available from: https://pjammcycling.com/triathlon/34.IRONMAN-Tallinn-Estonia (accessed March 10, 2024).
[25] Nowak BM, Ptak M, Stanek P. Influence of a lake on river water thermal regime: a case study of Lake Sławianowskie and the Kocunia River (Pomeranian Lakeland, North Poland). Meteorol Hydrol Water Manage. 2020;8(1):78–83; doi: 10.26491/mhwm/115222.
[26] Barbosa TM, Costa MJ, Morais JE, Morouço P, Moreira M, Garrido ND, Marinho DA, Silva AJ. Characterization of speed fluctuation and drag force in young swimmers: a gender comparison. Hum Mov Sci. 2013;32(6):1214–25; doi: https://doi.org/10.1016/j.humov.2012.07.009.
[27] Crouch TN, Burton D, LaBry ZA, Blair KB. Riding against the wind: a review of competition cycling aerodynamics. Sports Eng. 2017;20(2):81–110; doi: 10.1007/s12283-017-0234-1.
[28] Hoogkamer W, Taboga P, Kram R. Applying the cost of generating force hypothesis to uphill running. Peer J. 2014;2:e482; doi: 10.7717/peerj.482.
[29] Saycell J, Lomax M, Massey H, Tipton M. Scientific rationale for changing lower water temperature limits for triathlon racing to 12°C with wetsuits and 16°C without wetsuits. Br J Sports Med. 2018;52(11):702–8; doi: 10.1136/bjsports-2017-098914.

[30] Beaumont F, Bogard F, Murer S, Polidori G, Madaci F, Taiar R. How does aerodynamics influence physiological responses in middle-distance running drafting? Math Modelling Eng Prob. 2019;6(1):129–35; doi: 10.18280/mmep.060117.
[31] Lepers R, Knechtle B, Stapley PJ. Trends in triathlon performance: effects of sex and age. Sports Med. 2013;43(9):851–63; doi: 10.1007/s40279-013-0067-4.
[32] Heydenreich J, Kayser B, Schutz Y, Melzer K. Total energy expenditure, energy intake, and body composition in endurance athletes across the training season: a systematic review. Sports Med Open. 2017;3(1):8; doi: 10.1186/s40798-017-0076-1.