Where are the world's fastest Ironman® 70.3 race courses for professional athletes?

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Original Article

Where are the world's fastest Ironman® 70.3 race courses for professional athletes?

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Abstract: The dominance of certain nations in certain sports disciplines is well knowed in scientific context. For triathlon, it has been reported that most of the finishers, and the fastest in Ironman® Hawaii originated from the United States of America. However, nothing is known regarding the role of specific race courses in athletes' performance. The present study aimed to analyze where the fastest split and overall race times for Ironman® 70.3 races were achieved. The locations of the fastest Ironman® 70.3 competitions were processed throughout 163 different event locations. Race records were aggregated by location, and the split and full finish times. The Ironman® 70.3 races in Dubai, Kronborg, and Mandurah presented the fastest race course. For split disciplines, the fastest swim times were recorded for women and men in the Ironman® 70.3 races in Busan, Panama, and Augusta. For cycling, the fastest times were achieved for both women and men in Ironman® 70.3 Tallinn, followed by the Ironman® 70.3 Dubai and Bahrain. The fastest running times were recorded for women and men in Ironman® 70.3 Kronborg, the Ironman® 70.3 Nice, and Les Sables d'Olonne. Differences among the race course were found, except for the running discipline. Professional triathletes and coaches could use this information to design optimal race courses and training strategies for performance improvement.

Keywords: endurance, cycling, half-distance ironman, multi-sport, swimming, triathlon.

1. Introduction

Triathlon is a multi-sports discipline consisting of various distances of swimming, cycling, and running (e.g., Ironman® Hawaii, Olympic distance triathlon). Long-distance triathlon races such as the 'Ironman® Hawaii' (3.8 km swimming, 180 km cycling, and 42.195 km running) are very popular (Lepers, 2008). Apart from the 'Ironman® Hawaii' held annually as the World Championship in Ironman® triathlon, the Olympic distance triathlon (1.5 km swimming, 40 km cycling, and 10 km running) has been known to a broader audience since its inauguration in the Olympic Games (www.triathlon.org). In recent years, the half-Ironman distance – also called Ironman® 70.3 – has become increasingly popular (www.ironman.com/im703-races). The Ironman® 70.3 refers to the total distance in miles (113.0 km) covered in the race, consisting of a 1.2-mile (1.9 km) swim, a 56-mile (90 km) bike ride, and a 13.1-mile (21.1 km) run. Each distance of the swimming, cycling, and running segments is half the distance of that segment in a full Ironman distance triathlon.

It is also well-known that athletes from a specific region dominate certain sports disciplines. For example, athletes from East Africa (*i.e.,* Ethiopia and Kenya) dominate long-distance running, such as marathon running (World Athletics, 2022), while the runners from Jamaica are the fastest in the sprints (Campbell et al., 2019; Irving, Charlton, Morrison, Facey, & Buchanan, 2013). Furthermore, it has been shown that athletes from Russia were the fastest in specific ultra-marathon running races (*i.e.,* 100-km ultra-marathon and Comrades Marathon) and in certain cross-country skiing races (*i.e.,* Vasaloppet and Engadin Ski Marathon) (B. Knechtle, Rosemann, & Nikolaidis, 2020). For triathlon, it has been reported that most of the finishers in Ironman® Hawaii originated from the United States of America, and the fastest women and men also originated from the United States of America (P. Dähler, C. A. Rüst, T. Rosemann, R. Lepers, & B. Knechtle, 2014; Rüst et al., 2015).

Although we have some knowledge about the dominance of certain nations in certain sports disciplines, nothing is known regarding the role of specific race courses in athletes' performance. Most studies performed to understand the association between countries and performance are centered on athletes. Also, an extensive search in literature databases showed no scientific research on whether athletes travel to a specific race course to achieve a fast race time. This information could be essential because, in the case of marathons, there are events that are known to be faster than others due to altimetry and weather conditions. For example, George Marathon, St. George, Utah, USA, and Mendoza Marathon, Argentina, are races known for being fast races as there are many downhill runs and favorable climatic conditions. Considering that triathlon is also a sport mainly dependent on weather conditions and the altitude of the race, it is expected that in certain regions with advantageous topographic characteristics and environmental conditions, the races will be much faster than in others. For Ironman triathletes, popular websites presented the races where the best elite and age group times were achieved (www.triathlete.com/events/fastest-ironman-courses-youll-have-to-travel/; https://sportcoaching.co.nz/easiest-ironman-course-updated-2020/). Therefore, the present study aimed to analyze where the fastest split and overall race times for the Ironman® 70.3 were achieved. We assumed that races held in the United States of America, which was the origin of the Ironman® competition, and the best athletes in Ironman® 70.3 races are the fastest.

2. Methods

2.1 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.

2.2 Data set and data preparation

The athlete and race data were downloaded from the official Ironman website (www.ironman.com) using a python script. The athletes' sex, age group, country of origin, event location and year, and times for swimming, running, cycling, and transitioning were thus obtained. Age group information was not available for PRO athletes. We analyzed successful elite (professional) finishers of all Ironman® 70.3 races recorded on the Ironman® website (www.ironman.com) between 2004 and 2020. To register as an elite, the athlete should apply in the Ironman® community to become a "PRO" member with a copy of the athlete's license status as a professional athlete in the respective national triathlon federation member and must be affiliated in the International Triathlon Union (www.triathlon.org). Data considered for analysis were the time of each split discipline of Ironman® 70.3 distance (swimming, cycling, and running), and the overall race time (all in seconds).

2.3 Statistical analysis

To investigate the locations of the fastest Ironman® 70.3 competitions between 2004 and 2020, a total sample of 16,611 qualifying PRO records were processed. The race records were aggregated by location, and then the statistical values (mean, std, max and min) of split and full finish times were calculated for each location. Results are presented using strip plots that graphically show the distribution of full and split times in each location by gender, along with detailed tables with descriptive statistical values. Both tables and charts are sorted by mean times to identify the fastest locations easily. The statistical significance of the differences observed is then tested positively using two-wayANOVA tests and posthoc Tukey's HSD tests. The significance level was set at 0.05% in all cases. All data processing and analysis were performed using Python (www.python.org/) and a Google Colab notebook (https://colab.research.google.com/).

3. Results

A total of 16,611 PRO tri-athletes of both sexes, from 97 different countries, competing in 163 different event locations were sampled and analyzed. Figure 1 presents the histograms for performance in both sexes, with a higher frequency of males presenting a faster overall race time. Table 1 presents the details (i.e., general weather conditions, the topography of swimming, cycling, and running courses) of the race courses with the most successful finishers**.**

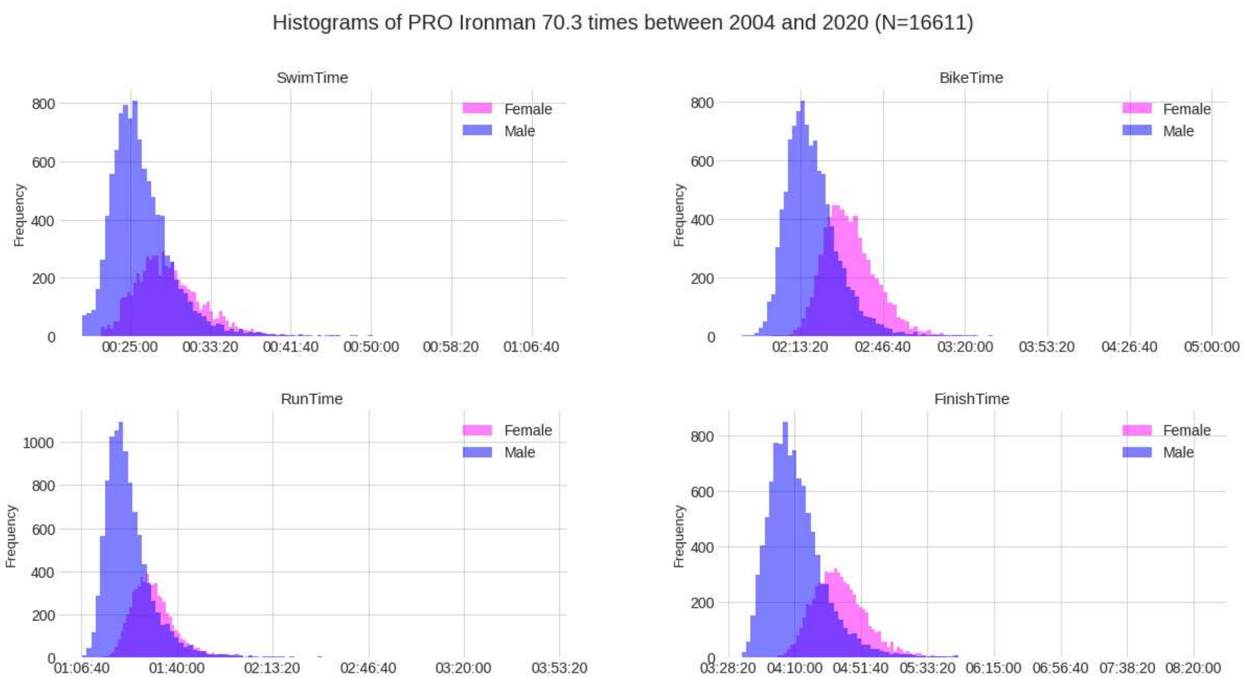

Figure 1. Histograms of Ironman 70.3 elite athletes finish times.

Table 1. Specific descriptions of Ironman® 70.3 race courses

Race	Month	Average temperature	Swimming characteristics	Cycling course characteristics	Running course characteristics
IRONMAN® 70.3 Zell am See	August	19°C	1 lap of 1.9 km in a lake	1 lap of 90 km, altitude difference of 1270 m per lap, overall altitude difference of 1270 m	2 laps of 21.1 km, altitude difference of 26 m per lap, at an overall altitude difference of 52 m
IRONMAN® 70.3 Kronborg	June	21°C	1 lap of 1.9 km in a bay	1 lap of 90 km, altitude difference of 600 m per lap, overall altitude difference of 600 m	3,5 laps of 21.1 km, altitude difference of 28,6 m per lap, at an overall altitude difference 100 m
IRONMAN® 70.3 Greece Costa Navarino	October	23°C	1 lap of 1.9 km in the ocean	2 laps of 90 km, altitude difference of 540 m per lap, overall altitude difference of 1080 m	3 laps of 21.1 km, altitude difference of 66,7 m per lap, at an overall altitude difference 200 m
IRONMAN® 70.3 Indian Wells La Quinta	December	18°C	1 lap of 1.9 km in a lake	1 lap of 90 km, altitude difference of 161 m per lap, overall altitude difference of 161 m	2 laps of 21.1 km, altitude difference of 57,7 m per lap, at an overall altitude difference of 115 m
IRONMAN® 70.3 Bahrain	December	22°C	1 lap of 1.9 km in a bay	1 lap of 90 km, altitude difference of 300 m per lap, overall altitude difference of 300 m	3 laps of 21.1 km, altitude difference of 24,3 m per lap, at an overall altitude difference 73 m
IRONMAN® 70.3 Texas	April	21°C	1 lap of 1.9 km in a bay	1 lap of 90 km, altitude difference of 45 m per lap, overall altitude difference of 45 m	3 laps of 21.1 km, altitude difference of 10,7 m per lap, at an overall altitude difference 32 m
IRONMAN® 70.3 Tallinn	August	17°C	1 lap of 1.9 km in a lake	1 lap of 90 km, altitude difference of 300 m per lap, overall altitude difference of 300 m	2 laps of 21.1 km, altitude difference of 57,7 m per lap, at an overall altitude difference of 115 m
IRONMAN® 70.3 Western Sydney	September	23°C	1 lap of 1.9 km in a lake	2 laps of 90 km, altitude difference of 165 m per lap, overall altitude difference of 330 m	1 lap of 21.1 km, altitude difference of 25 m per lap, at an overall altitude difference of 25 m
IRONMAN® 70.3 Maceio	August	28°C	1 lap of 1.9 km in the ocean	1 lap of 90 km, altitude difference of 200 m per lap, overall altitude difference of 200 m	3 laps of 21.1 km, altitude difference of 23,3 m per lap, at an overall altitude difference 70 m
IIRONMAN® 70.3 Liuzhou	September	28°C	1 lap of 1.9 km in a river	2 laps of 90 km, altitude difference of 168,5 m per lap, overall altitude difference of 337 m	2 laps of 21.1 km, altitude difference of 171 m per lap, at an overall altitude difference of 342 m
IRONMAN® 70.3 Luxembourg	June	18°C	1 lap of 1.9 km in a river	1 lap of 90 km, altitude difference of 580 m per lap, overall altitude difference of 580 m	2,5 laps of 21.1 km, altitude difference of 40 m per lap, at an overall altitude difference of 100 m
IRONMAN® 70.3 Marbella	May	21°C	1 lap of 1.9 km in the ocean	1 lap of 90 km, altitude difference of 1400 m per lap, overall altitude difference of 1400 m	2 laps of 21.1 km, altitude difference of 25 m per lap, at an overall altitude difference of 50 m
IRONMAN® 70.3 Vichy	August	28°C	1 lap of 1.9 km in a lake	1 lap of 90 km, altitude difference of 1000 m per lap, overall altitude difference of 1000 m	2 laps of 21.1 km, altitude difference of 50 m per lap, at an overall altitude difference of 100 m

Table 1. Specific descriptions of Ironman® 70.3 race courses (continued)

Race	Month	Average temperature	Swimming characteristics	Cycling course characteristics	Running course characteristics
IRONMAN® 70.3 Gdynia	August	25°C	1 lap of 1.9 km in a bay	1 lap of 90 km, altitude difference of 1860 m per lap, overall altitude difference of 1860 m	2 laps of 21.1 km, altitude difference of 70 m per lap, at an overall altitude difference of 340 m
IRONMAN® 70.3 Mallorca	May	25°C	1 lap of 1.9 km in the ocean	1 lap of 90 km, altitude difference of 850 m per lap, overall altitude difference of 850 m	3 laps of 21.1 km, altitude difference of 20 m per lap, at an overall altitude difference 60 m
IRONMAN 70.3 Panama	March	30°C	1 lap of 1.9 km in the ocean	3 laps of 90 km	3 laps of 21.1 km
IRONMAN 70.3 Augusta	September	27°C	1 lap of 1.9 km in the river	1 lap of 90 km	2 laps of 21.1 km
IRONMAN 70.3 North Carolina	October	18°C	1 lap of 1.9 km in the ocean	1 lap of 90 km	1 lap of 21.1 km
IRONMAN 70.3 Dubai	March	24°C	1 lap of 1.9 km in the ocean	1 lap of 90 km, altitude difference of 87 m per lap, overall altitude difference of 87 m	1,5 laps of 21.1 km, altitude difference of 5 m per lap, at an overall altitude difference 7,5 m
IRONMAN 70.3 Sao Paolo	September	25°C	1 lap of 1.9 km in a reservoir	2 laps of 90 km, altitude difference of 20 m per lap, overall altitude difference of 40 m	3 laps of 21.1 km, altitude difference of 15 m per lap, at an overall altitude difference 45 m
IRONMAN 70.3 Alagolas	August	28°C	1 lap of 1.9 km in the ocean	1 lap of 90 km, altitude difference of 100 m per lap, overall altitude difference of 100 m	3 laps of 21.1 km, altitude difference of 20 m per lap, at an overall altitude difference 60 m
IRONMAN 70.3 Emilia Romagna	September	25°C	1 lap of 1.9 km in the ocean	1 lap of 90 km, altitude difference of 185 m per lap, overall altitude difference of 185 m	3 laps of 21.1 km, altitude difference of 5 m per lap, at an overall altitude difference 15 m
IRONMAN 70.3 Pays D'Aix	May	20°C	1 lap of 1.9 km in a lake	1 lap of 90 km, altitude difference of 390 m per lap, overall altitude difference of 390 m	3 laps of 21.1 km, altitude difference of 15 m per lap, at an overall altitude difference 45 m
IRONMAN 70.3 Sunshine Coast	September	26°C	1 lap of 1.9 km in the ocean	2 laps of 90 km, altitude difference of 35 m per lap, overall altitude difference of 70 m	2 laps of 21.1 km, altitude difference of 20 m per lap, at an overall altitude difference 40 m
IRONMAN 70.3 Geelong	March	19°C	1 lap of 1.9 km in a bay	2 laps of 90 km, altitude difference of 75 m per lap, overall altitude difference of 150 m	2,5 laps of 21.1 km, altitude difference of 25 m per lap, at an overall altitude difference 67 m
IRONMAN 70.3 Steelhead	Juna	20°C	1 lap of 1.9 km in a lake	1 lap of 90 km	2 laps of 21.1 km
IRONMAN 70.3 Turkey	November	24°C	2 laps of 1.9 km in the ocean	2 laps of 90 km, altitude difference of 20 m per lap, overall altitude difference of 40 m	3 laps of 21.1 km, altitude difference of 5 m per lap, at an overall altitude difference 15 m

Table 1. Specific descriptions of Ironman® 70.3 race courses (continued)

Race	Month	Average temperature	Swimming characteristics	Cycling course characteristics	Running course characteristics
IRONMAN 70.3 California	April	17°C	1 lap of 1.9 km in the ocean	1 lap of 90 km, altitude difference of 220 m per lap, overall altitude difference of 220 m	2 laps of 21.1 km, altitude difference of 10 m per lap, at an overall altitude difference 20 m
IRONMAN 70.3 Astana	June	25°C	1 lap of 1.9 km in a river	1 lap of 90 km, altitude difference of 20 m per lap, overall altitude difference of 20 m	2 laps of 21.1 km, altitude difference of 5 m per lap, at an overall altitude difference 10 m
IRONMAN 70.3 Florianapolis	April	21°C	1 lap of 1.9 km in the ocean	1 lap of 90 km	3 laps of 21.1 km

Table 2 summarizes the ten fastest destinations sorted by overall race and split times. The fastest overall race times were achieved for both women and men in Ironman® 70.3 Dubai (United Arab Emirates), followed by the Ironman® 70.3 Kronborg (Denmark) and Ironman® 70.3 Mandurah (Australia) (Figure 2). The ANOVA two-way results indicate that the differences in the mean finish times between different locations are statistically significant ($p<0.05$). The Tukey tests result in one single pair of race courses statistically different, being the first (Dubai) and the last (Buenos Aires) in the top 10 rank of fastest full race times (diff = 486.67; IC95% = 43.49; 929.84) (table 3).

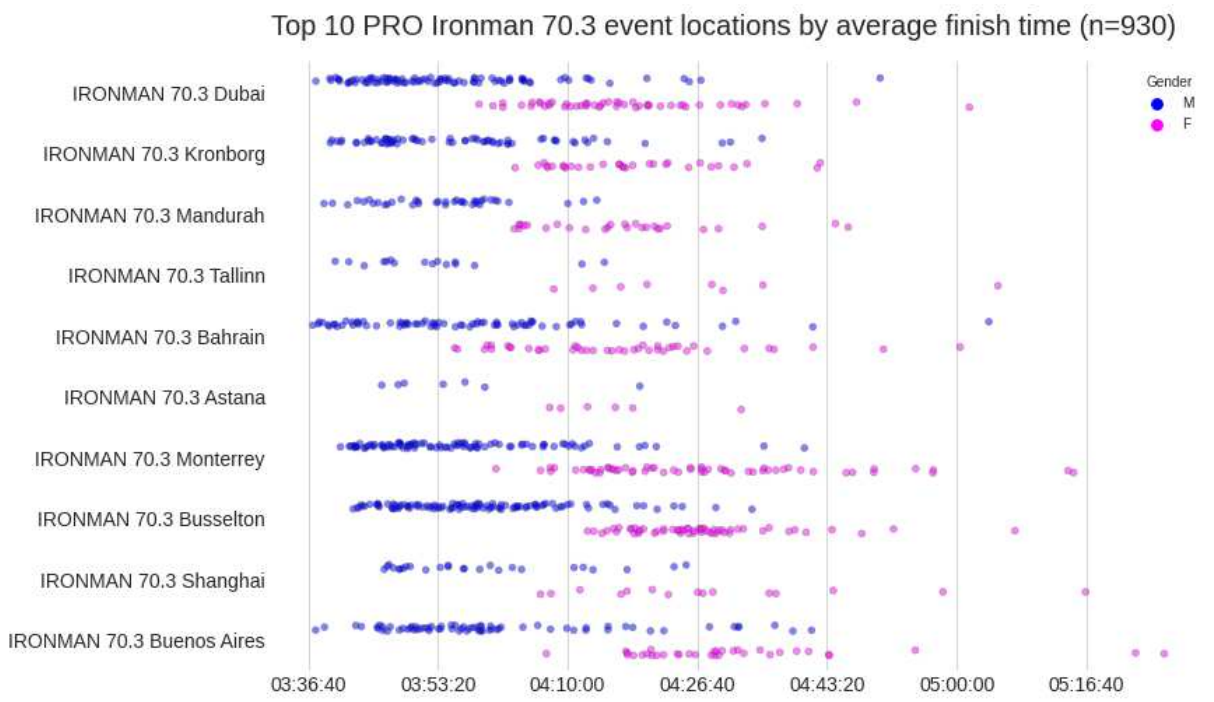

Figure 2.The 10 fastest race courses by average time [by gender]

Table 2. Split and overall race times of the top 10 race courses

				Finish Time		
	Event Location	**count**	**mean**	**std**	**max**	**min**
1	IRONMAN® 70.3 Dubai	146	04:02:43	00:16:26	05:01:38	03:37:40
2	IRONMAN® 70.3 Kronborg	101	04:02:56	00:15:41	04:42:28	03:39:31
3	IRONMAN® 70.3 Mandurah	66	04:03:29	00:15:13	04:46:03	03:38:42
4	IRONMAN® 70.3 Tallinn	24	04:04:08	00:20:50	05:05:18	03:40:08
5	IRONMAN® 70.3 Bahrain	118	04:04:25	00:17:49	05:04:08	03:37:15
6	IRONMAN®70.3 Astana	13	04:05:18	00:14:16	04:32:19	03:46:08
7	IRONMAN®70.3 Monterrey	154	04:08:00	00:20:27	05:15:01	03:40:49
8	IRONMAN®70.3 Busselton	163	04:08:29	00:17:02	05:07:29	03:42:27
9	IRONMAN®70.3 Shanghai	41	04:09:58	00:20:47	05:16:33	03:46:26
10	IRONMAN®70.3 Buenos Aires	104	04:10:49	00:21:10	05:26:40	03:37:38
				Swim time		
		count	**mean**	**std**	**max**	**min**
1	IRONMAN®70.3 Busan	4	00:21:33	00:01:40	00:23:35	00:20:07
2	IRONMAN®70.3 Panama	65	00:23:00	00:02:11	00:29:38	00:20:02
3	IRONMAN®70.3 Augusta	224	00:23:06	00:02:18	00:41:53	00:20:01
4	IRONMAN®70.3 Mandurah	66	00:23:07	00:02:07	00:27:48	00:20:09
5	IRONMAN®70.3 Liuzhou	45	00:24:26	00:02:54	00:31:19	00:20:03
6	IRONMAN®70.3 Incheon Korea	14	00:24:34	00:02:01	00:28:25	00:22:07
7	IRONMAN®70.3 Kronborg	101	00:24:42	00:02:37	00:32:08	00:21:02
8	IRONMAN®70.3 Port Macquarie	86	00:24:43	00:02:25	00:30:38	00:20:01
9	IRONMAN®70.3 Marbella	71	00:24:53	00:04:23	00:47:42	00:20:03
10	IRONMAN®70.3 Geelong	142	00:24:57	00:02:31	00:33:34	00:20:46
				Bike time		
		count	**mean**	**std**	**max**	**min**
1	IRONMAN®70.3 Tallinn	24	02:09:45	00:08:08	02:21:34	01:57:30
2	IRONMAN®70.3 Dubai	146	02:10:01	00:08:29	02:51:45	01:53:35
3	IRONMAN®70.3 Bahrain	118	02:10:17	00:09:44	02:55:52	01:52:01
4	IRONMAN®70.3 Astana	13	02:11:47	00:08:09	02:30:22	02:00:33
5	IRONMAN®70.3 Kronborg	101	02:12:29	00:07:51	02:37:15	02:01:14
6	IRONMAN®70.3 Mandurah	66	02:12:38	00:07:51	02:34:41	02:00:23
7	IRONMAN®70.3 Shanghai	41	02:13:28	00:10:50	02:47:07	02:00:33
8	IRONMAN®70.3 Gulf Coast	25	02:13:29	00:08:46	02:32:10	02:01:00
9	IRONMAN®70.3 Brazil	72	02:13:58	00:10:33	02:51:11	01:59:03
10	IRONMAN®70.3 Ruegen	112	02:14:11	00:09:23	02:41:04	02:00:51
				Run time		
		count	**mean**	**std**	**max**	**min**
1	IRONMAN®70.3 Kronborg	101	01:20:25	00:06:39	01:44:01	01:07:45
2	IRONMAN®70.3 Nice	108	01:20:51	00:07:00	01:41:46	01:08:10
3	IRONMAN®70.3 Les Sables d'Olonne	62	01:21:05	00:07:11	01:42:29	01:11:25
4	IRONMAN®70.3 Vichy	98	01:21:16	00:06:39	01:46:42	01:08:19
5	IRONMAN®70.3 Haugesund / Norway	88	01:21:20	00:06:58	01:57:21	01:08:40
6	IRONMAN®70.3 Florianopolis	33	01:21:35	00:06:11	01:34:08	01:11:27
7	IRONMAN®70.3 Dubai	146	01:21:50	00:07:25	01:52:26	01:08:22
8	IRONMAN®70.3 Pays D'Aix	263	01:22:02	00:09:02	02:34:25	01:06:50
9	IRONMAN®70.3 Pula	5	01:22:13	00:03:58	01:27:45	01:17:36
10	IRONMAN®70.3 Aarhus	15	01:22:17	00:03:48	01:29:37	01:15:17

For split disciplines, the fastest swim times were recorded for both women and men in Ironman® 70.3 Busan, Ironman® 70.3 Panama, and Ironman® 70.3 Augusta (Figure 3). For cycling, the fastest times were achieved for both women and men in Ironman® 70.3 Tallinn (Austria), followed by the Ironman® 70.3 Dubai (United Arab Emirates) and Ironman® 70.3 Bahrain (Middle East) (Figure 4). The fastest running times were recorded for both women and men in Ironman® 70.3 Kronborg (Denmark), the Ironman® 70.3 Nice (France), and Ironman® 70.3 Les Sables d'Olonne (France) (Figure 5). ANOVA two-way results indicate that the differences in the mean finish times between different locations and sex are statistically significant for swimming and cycling ($p<0.05$) but not for running. Multiple pairwise post hoc test results for comparison between race courses are presented in Table 3. For running, the results are not statistically significant between race courses ($p=0.766$).

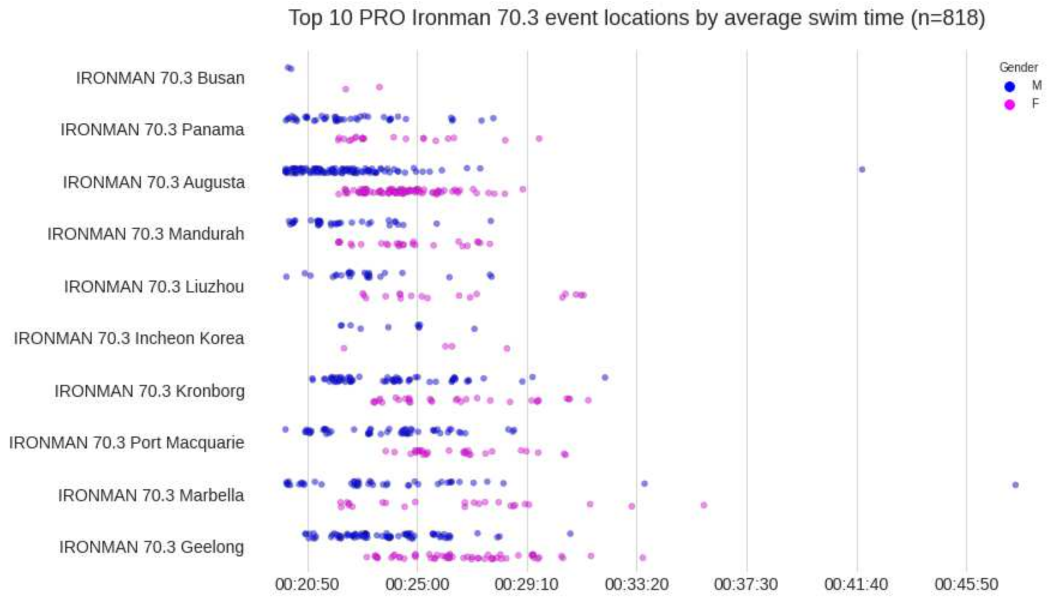

Figure 3. The 10 fastest swimming courses regarding all women and men

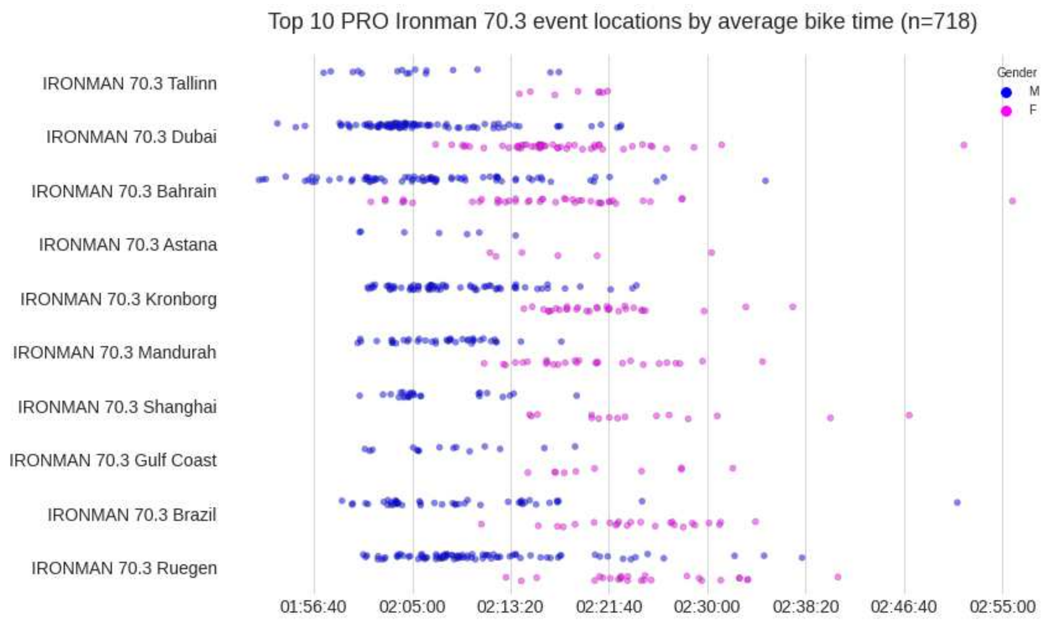

Figure 4. The 10 fastest cycling courses regarding all women and men

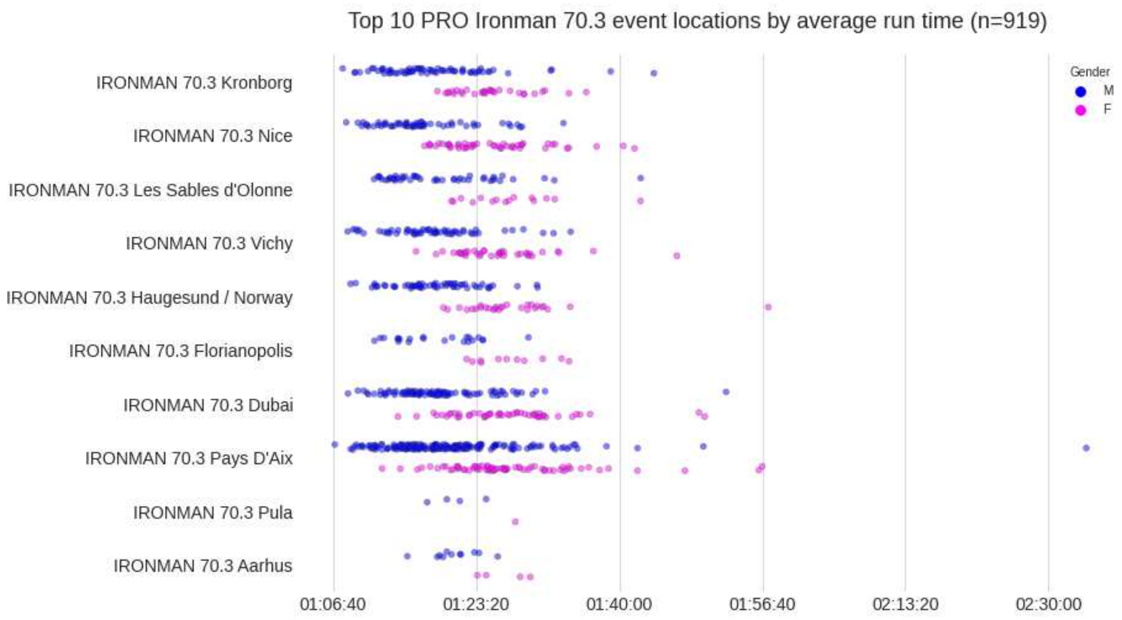

Figure 5. The 10 fastest running courses regarding all women and men

Table 3. Multiple pairwise post hoc tests results for comparison between race courses, for partial and full times

Group 1	Group 2	Diff	Lower	Upper	q-value	p-value
	Average finish time					
IRONMAN® 70.3 Dubai	IRONMAN® 70.3 Buenos Aires	486.67	43.49	929.84	4.93	0.02
	Swimming time					
IRONMAN® 70.3 Panama	IRONMAN® 70.3 Kronborg	102.69	22.65	182.73	5.76	2.09E-03
IRONMAN® 70.3 Panama	IRONMAN® 70.3 Marbella	113.2	26.79	199.62	5.88	1.47E-03
IRONMAN® 70.3 Panama	IRONMAN® 70.3 Geelong	117.04	41.66	192.42	6.97	1.00E-03
IRONMAN® 70.3 Panama	IRONMAN® 70.3 Port Macquarie	103.59	20.86	186.32	5.62	3.09E-03
IRONMAN® 70.3 Kronborg	IRONMAN® 70.3 Augusta	96.49	36.16	156.82	7.18	1.00E-03
IRONMAN® 70.3 Kronborg	IRONMAN® 70.3 Mandurah	95.47	15.79	175.14	5.38	5.97E-03
IRONMAN® 70.3 Marbella	IRONMAN® 70.3 Augusta	107	38.45	175.56	7	1.00E-03
IRONMAN® 70.3 Marbella	IRONMAN® 70.3 Mandurah	105.98	19.91	192.05	5.52	3.99E-03
IRONMAN® 70.3 Geelong	IRONMAN® 70.3 Augusta	110.84	56.85	164.84	9.21	1.00E-03
IRONMAN® 70.3 Geelong	IRONMAN® 70.3 Mandurah	109.82	34.83	184.81	6.57	1.00E-03
IRONMAN® 70.3 Augusta	IRONMAN® 70.3 Port Macquarie	97.39	33.53	161.24	6.84	1.00E-03
IRONMAN® 70.3 Port Macquarie	IRONMAN® 70.3 Mandurah	96.36	13.99	178.74	5.25	8.33E-03
	Cycling time					
IRONMAN® 70.3 Dubai	IRONMAN® 70.3 Ruegen	249.93	32.81	467.04	5.17	0.01
IRONMAN® 70.3 Bahrain	IRONMAN® 70.3 Ruegen	234.60	6.58	462.62	4.62	0.04

4. Discussion

The study aimed to analyze where the Ironman® 70.3 races were held, considering where both split and overall race times were achieved. The most important finding was that the overall fastest results were achieved in races held in European countries, with sub-representativeness of Africa, Oceania, and South American continents. Differences among the race course were found, except for the running discipline. These results reject our hypothesis that events hosted in the USA were the fastest.

The last years showed an increase in participation for athletes competing in Ironman from different continents, especially South America and Africa (Philippe Dähler, Christoph Alexander Rüst, Thomas Rosemann, Romuald Lepers, & Beat Knechtle, 2014). However, this increase is not related to performance or hosting events. To investigate race courses is a challenging task since the factors that explain the results are not well presented in the scientific literature. Therefore, moving forward with an individual approach that considers the intra and interpersonal factors as the most important factors to athletes' achievement, our results reflected that natural, climatic, and economic conditions of different countries hosting Ironman® 70.3 events should also be considered for both individual and environmental benefits. In a similar context, for the Olympic marathon, previous research showed a global decrease of about 27% in the number of cities that could host the Olympic marathon in future events (Oyama, Takakura, Fujii, Nakajima, & Hijioka, 2022). These results were related to climatic and socioeconomic changes (Oyama et al., 2022).

For the present study, lower temperatures and dynamic terrain seemed important characteristics of some race courses. Previous studies highlighted the negative effect of heat on endurance athletes' performance (Helou et al., 2012; Nikolaidis et al., 2019; Weiss et al., 2022), where faster race times were observed in years with lower temperatures. These studies mentioned that exposure to higher temperatures is related to increases in the core temperature (Laursen et al., 2006) and performance decrease (Chabert, Hermand, & Hue, 2019; Helou et al., 2012; Beat Knechtle, Valero, Villiger, Alvero-Cruz, et al., 2021). Furthermore, a combination of high humidity and ambient temperature would accentuate greater physiological strains and decrease endurance performance (Lei & Wang, 2021).

Besides the influence of weather characteristics on Ironman athletes, most of the studies investigating climatic aspects and endurance performance were performed in the context of running (Beat Knechtle, Valero, Villiger, Alvero-Cruz, et al., 2021; Beat Knechtle, Valero, Villiger, Alvero Cruz, et al., 2021; Nikolaidis et al., 2019; Weiss et al., 2022). These characteristics make comparisons difficult and suggest that investigating the effect of wheatear characteristics on Ironman athletes' performance is an emergent topic. This is particularly important considering divergent results findings in the present study, in which top participants and younger age groups performed better on courses with higher temperatures.

Considering split disciplines, the main findings showed that a better swimming performance was achieved in geographically protected and calm waters where the course was straight with a minimum of turns. These results can be related to the environmental challenges of the rivers, lakes, oceans, and water channels for athletes, as well as the technical requirements for swimming (Baldassarre, Bonifazi, Zamparo, & Piacentini, 2017). As a discipline performed in outdoor/aquatic space, water characteristics (i.e., temperature, protection) can also impair athletes' performance. A minimal number of turns might favor performance due to stability in the metabolic demands of swimming since it was assumed that an increased number of turns would cause an additional metabolic cost. Furthermore, swimming in hot water would induce significant physiological strain (Chalmers, Shaw, Mujika, & Jay, 2021), such as increased oxygen uptake, blood lactate concentrations, rate of perceived exertion, maximal heart rate, and energy cost (Gay et al., 2021), and consequently, deteriorate performance. In another way, cyclists were befitted with rolling terrain and a flat course (top performers). The association between terrain and cycling performance was not explored previously. However, a flat course seems to be positively associated with performance, given that athletes decrease the metabolic cost (Hoogkamer, Taboga, & Kram, 2014; Margaria, Cerretelli, Aghemo, & Sassi, 1963). Otherwise, the characteristics of Ironman® 70.3 race courses, i.e., if they are flat courses in which athletes are constantly in the presence of other cyclists, can be associated with performance, and trend to favor athletes cycling in pelotons to spend less energy and to sustain higher speed (Crouch, Burton, LaBry, & Blair, 2017; Kyle, 1979). Similar results are related to running, in which race courses with flat track favor athletes' performance. Previous studies highlighted the higher metabolic energy supply rate of running uphill (Hoogkamer et al., 2014). In addition, running in a curved path generate a centripetal force on the ground, meaning an increment in runners' metabolic cost, comparatively a straight course (Snyder et al., 2021). Besides, in a different context than Ironman athletes, the effect of the race course on athletes' performance can also be visualized in the break of the 2-hour barrier in Marathon - Vienna, 2019 (Snyder et al., 2021).

This study was not free of limitations. The first important limitation is the lack of information about the place of competition and the country of residence for each participant. Previous studies showed that athletes' who live in nations that host more competitions over time are more likely to compete since the associated costs and stress of travel are lower. This may explain the greater participation of Americans in Ironman ® World Championship that always take place in the United States (Kona, Hawaii). Unlike the Ironman® 70.3 World Championship, which take place in different countries on different continents, and which do not have an American majority in participation. In addition, familiarity with geographic factors and the race course should be considered. Another point was the lack of information regarding the economic and stakeholders' support for hosting sports events. Ironman® and Ironman® 70.3 events were characterized by a higher cost, considering participants' security and the built and natural environment, meaning that some places were better prepared to receive these events than others. These characteristics were related to inequalities between countries regarding the possibility of hosting events.

5. Practical application

Perhaps the main approach in sports geography included the study of genetic and environmental characteristics associated with athletes' performance in specific countries (Wilber & Pitsiladis, 2012; Zani et al., 2022), and the results of the present study moved forward this approach to show where the fastest race times were achieved. This was a change of perspective, considering how the geographical characteristics influenced athletes' performance (Marc et al., 2017; Song & Zhang, 2018), and could be regarded as for coaches' and elite athletes' schedule periodization. Specifically, based on cost-benefits, the athletes' team could use this information to design the best race course and training strategies for performance improvement, as well as, at the international level, this information can provide insights regarding courses in which athletes tend to break records.

The fastest Ironman® 70.3 courses were situated in the northern hemisphere with lower temperatures and dynamic terrain. Differences in courses based on discipline were found, which a better swimming performance achieved in protected and calm waters, rolling terrain for cycling, and a flat track for running. Professional Ironman® 73 triathletes and their coaches could use this information to plan to travel to an optimal race course and training strategies for performance improvement. Furthermore, this information can provide insights regarding courses where athletes may aim to break personal records and/or to qualify for the Ironman® 70.3 World Championships.

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References

Baldassarre, R., Bonifazi, M., Zamparo, P., & Piacentini, M. F. (2017). Characteristics and Challenges of Open-Water Swimming Performance: A Review. *International Journal of Sports Physiology and Performance, 12*(10), 1275-1284. https://doi.org/10.1123/ijspp.2017-0230

Campbell, E., Irving, R., Poudevigne, M., Dilworth, L., McFarlane, S., Ismail, O., & Bailey, J. (2019). Contextual factors and sporting success: The relationship between birth date and place of early development on the progression of Jamaican track and field athletes from junior to senior level. *PLoS One, 14*(12), e0227144. https://doi.org/10.1371/journal.pone.0227144

Chabert, C., Hermand, E., & Hue, O. (2019). Triathlon and Ultra-Endurance Events in Tropical Environments. *Springer International Publishing*, 283-296. https://doi.org/10.1007/978-3-319-93515-7_15

Chalmers, S., Shaw, G., Mujika, I., & Jay, O. (2021). Thermal Strain During Open-Water Swimming Competition in Warm Water Environments. *Frontiers in physiology, 12*, 785399. https://doi.org/10.3389/fphys.2021.785399

Crouch, T. N., Burton, D., LaBry, Z. A., & Blair, K. B. (2017). Riding against the wind: a review of competition cycling aerodynamics. *Sports Engineering, 20*(2), 81-110. https://doi.org/10.1007/s12283-017-0234-1

Dähler, P., Rüst, C. A., Rosemann, T., Lepers, R., & Knechtle, B. (2014). Nation related participation and performance trends in 'Ironman Hawaii' from 1985 to 2012. *BMC Sports Sci Med Rehabil, 6*, 16. https://doi.org/10.1186/2052-1847-6-16

Dähler, P., Rüst, C. A., Rosemann, T., Lepers, R., & Knechtle, B. (2014). Nation related participation and performance trends in 'Ironman Hawaii' from 1985 to 2012. *BMC Sports Science, Medicine and Rehabilitation, 6*(1), 16. https://doi.org/10.1186/2052-1847-6-16

Gay, A., Zacca, R., Abraldes, J. A., Morales-Ortíz, E., López-Contreras, G., Fernandes, R. J., & Arellano, R. (2021). Swimming with Swimsuit and Wetsuit at Typical vs. Cold-water Temperatures (26 vs. 18 °C). *Int J Sports Med, 42*(14), 1305-1312. https://doi.org/10.1055/a-1481-8473

Helou, N. E., Tafflet, M., Berthelot, G., Tolaini, J., Marc, A., Guillaume, M., . . . Toussaint, J.-F. (2012). Impact of environmental parameters on marathon running performance. *PLoS One, 7*(5), e37407. https://doi.org/10.1371/journal.pone.0037407

Hoogkamer, W., Taboga, P., & Kram, R. (2014). Applying the cost of generating force hypothesis to uphill running. *PeerJ, 2*, e482. 10.7717/peerj.482

Irving, R., Charlton, V., Morrison, E., Facey, A., & Buchanan, O. (2013). Demographic characteristics of world class Jamaican sprinters. *ScientificWorldJournal, 2013*, 670217. https://doi.org/10.1155/2013/670217

Knechtle, B., Rosemann, T., & Nikolaidis, P. T. (2020). The Role of Nationality in Ultra-Endurance Sports: The Paradigm of Cross-Country Skiing and Long-Distance Running. *Int J Environ Res Public Health, 17*(7). https://doi.org/10.3390/ijerph17072543

Knechtle, B., Valero, D., Villiger, E., Alvero-Cruz, J. R., Nikolaidis, P. T., Cuk, I., . . . Scheer, V. (2021). Trends in Weather Conditions and Performance by Age Groups Over the History of the Berlin Marathon. *Frontiers in physiology, 12*. https://doi.org/10.3389/fphys.2021.654544

Knechtle, B., Valero, D., Villiger, E., Alvero Cruz, J. R., Scheer, V., Rosemann, T., & Nikolaidis, P. T. (2021). Elite Marathoners Run Faster With Increasing Temperatures in Berlin Marathon. *Frontiers in physiology, 12*. https://doi.org/10.3389/fphys.2021.649898

Kyle, C. (1979). Reduction of wind resistance and power output of racing cyclists and runners travelling in groups. *Ergonomics, 22*(4), 387–397.

Laursen, P. B., Suriano, R., Quod, M. J., Lee, H., Abbiss, C. R., Nosaka, K., . . . Bishop, D. (2006). Core temperature and hydration status during an Ironman triathlon. *Br J Sports Med, 40*(4), 320-325; discussion 325. https://doi.org/10.1136/bjsm.2005.022426

Lei, T. H., & Wang, F. (2021). Looking ahead of 2021 Tokyo Summer Olympic Games: How Does Humid Heat Affect Endurance Performance? Insight into physiological mechanism and heat-related illness prevention strategies. *J Therm Biol, 99*, 102975. https://doi.org/10.1016/j.jtherbio.2021.102975

Lepers, R. (2008). Analysis of Hawaii ironman performances in elite triathletes from 1981 to 2007. *Med Sci Sports Exerc, 40*(10), 1828-1834. https://doi.org/10.1249/MSS.0b013e31817e91a4

Marc, A., Sedeaud, A., Schipman, J., Jacquemin, J. A., Saulière, G., Kryger, K. O., & Toussaint, J. F. (2017). Geographic enrolment of the top 100 in athletics running events from 1996 to 2012. *J Sports Med Phys Fitness*, *57*(4), 418-425. https://doi.org/10.23736/s0022-4707.16.06019-9

Margaria, R., Cerretelli, P., Aghemo, P., & Sassi, G. (1963). Energy cost of running. *Journal of Applied Physiology*, *18*(2), 367-370. https://doi.org/10.1152/jappl.1963.18.2.367

Nikolaidis, P. T., Di Gangi, S., Chtourou, H., Rüst, C. A., Rosemann, T., & Knechtle, B. (2019). 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*, *16*(4). https://doi.org/10.3390/ijerph16040614

Oyama, T., Takakura, J. y., Fujii, M., Nakajima, K., & Hijioka, Y. (2022). Feasibility of the Olympic marathon under climatic and socioeconomic change. *Scientific Reports*, *12*(1), 4010. https://doi.org/10.1038/s41598-022-07934-6

Rüst, C. A., Bragazzi, N. L., Signori, A., Stiefel, M., Rosemann, T., & Knechtle, B. (2015). Nation related participation and performance trends in 'Norseman Xtreme Triathlon' from 2006 to 2014. *Springerplus*, *4*(1), 469. https://doi.org/10.1186/s40064-015-1255-5

Snyder, K. L., Hoogkamer, W., Triska, C., Taboga, P., Arellano, C. J., & Kram, R. (2021). Effects of course design (curves and elevation undulations) on marathon running performance: a comparison of Breaking 2 in Monza and the INEOS 1:59 Challenge in Vienna. *J Sports Sci*, *39*(7), 754-759. https://doi.org/10.1080/02640414.2020.1843820

Song, M., & Zhang, Y. (2018). Research on the Relationship between Geographical Factors, Sports and Culture. *Advances in Physical Education*, *8*, 66-70. https://doi.org/10.4236/ape.2018.81008

Thuany, M., Pereira, S., Hill, L., Santos, J. C., Rosemann, T., Knecthle, B., & Gomes, T. N. (2021). Where Are the Best European Road Runners and What Are the Country Variables Related to It? *Sustainability*, *13*(7781). https://doi.org/10.3390/su13147781

Weiss, K., Valero, D., Villiger, E., Thuany, M., Scheer, V., Cuk, I., & Knechtle, B. (2022). Temperature and barometric pressure are related to running speed and pacing of the fastest runners in the 'Berlin Marathon'. *Eur Rev Med Pharmacol Sci*, *26*(12), 4177-4287. https://doi.org/10.26355/eurrev_202206_29054

Wilber, R., & Pitsiladis, Y. (2012). Kenyan and Ethiopian distance runners: what makes them so good? *Int J Sports Physiol Perform*, *7*(2), 92-102. https://doi.org/10.1123/ijspp.7.2.92

World Athletics. (2022). What it takes to become a Kenyan distance champion. Retrieved from https://worldathletics.org/be-active/performance/kenyan-distance-running-reasons-success

Zani, A. L. S., Gouveia, M. H., Aquino, M. M., Quevedo, R., Menezes, R. L., Rotimi, C., . . . Fagundes, N. J. R. (2022). Genetic differentiation in East African ethnicities and its relationship with endurance running success. *PLoS One*, *17*(5), e0265625. https://doi.org/10.1371/journal.pone.0265625