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The fastest 24-hour ultramarathoners are from Eastern Europe

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Ultramarathon running is of increasing popularity, where the time-limited 24-hour run is one of the most popular events. Although we have a high scientific knowledge about different topics for this specific race format, we do not know where the best 24-hour runners originate from and where the fastest races are held. The purpose of the present study was to investigate the origin of these runners and the fastest race locations. A machine learning model based on the XG Boost algorithm was built to predict running speed based on the athlete´s age, gender, country of origin and the country where the race takes place. Model explainability tools were used to investigate how each independent variable would influence the predicted running speed. A sample of 171,358 race records from 63,514 unique runners from 73 countries participating in 24-hour races held in 57 countries between 1807 and 2022 was analyzed. Most of the athletes originated from the USA, France, Germany, Great Britain, Italy, Japan, Russia, Australia, Austria, and Canada. Tunisian athletes achieved the fastest average running speed, followed by runners from Russia, Latvia, Lithuania, Island, Croatia, Slovenia, and Israel. Regarding the country of the event, the ranking looks quite similar to the participation by the athlete, suggesting a high correlation between the country of origin and the country of the event. The fastest 24-hour races are recorded in Israel, Romania, Korea, the Netherlands, Russia, and Taiwan. On average, men were 0.4 km/h faster than women, and the fastest runners belonged to age groups 35–39, 40–44, and 45–49 years. In summary, the 24-hour race format is spread over the world, and the fastest athletes mainly originate from Eastern Europe, while the fastest races were organized in European and Asian countries.

Keywords Ultra-endurance, Nationality, Origin, Performance, Machine learning

Ultramarathons are highly popular and are held in different race formats, such as distance- or time-limited races[1]. In general, these races must be longer than the marathon distance (42.195 km) for distance-limited races and endure longer than 6 h for time-limited races[2].

The 24-hour format is one of the most popular time-limited races[3]. A 24-hour run is a form of ultramarathon in which competitors run as far as they can to cover the longest distance in 24 h. They are typically held on 1- to 2-mile/km loops or occasionally on 400-meter tracks. Depending on the conditions, the top runners often achieve 200 km or more, and the best can go beyond 290 km[4]. Often, 24-hour events are combined with 6-, 12-, 48-hour or even longer events[4].

The 24-hour run puts the body to physiological and psychological limits. Therefore, it is also of high scientific interest where different topics were investigated such as training[5,6] and experience[6], metabolic[7,8] and physiological

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aspects[7,9], anthropometric characteristics[10,11], energy metabolism[8], fluid metabolism[8] and exercise-associated hyponatremia[12], the age of peak performance[13], the sex difference in performance[14], aspects of cardiac[15], renal[16] and pulmonary, function, biomechanics such as pacing during a race[5], psychological and motivational aspects[17].

A 24-hour ultramarathon presents a compelling subject for research due to its unique combination of physical and mental challenges, offering valuable insights into human endurance and performance. The prolonged duration of the race allows scientists to examine the physiological responses of the human body to sustained activity, including factors such as energy expenditure, muscle fatigue, and recovery mechanisms. Furthermore, the mental resilience required for participants to navigate through such an extended race provides an opportunity to study the cognitive aspects of endurance sports, shedding light on the psychological strategies employed to maintain focus and motivation over an extended period. Understanding the intricacies of both physical and mental aspects during a 24-hour ultramarathon can contribute not only to sports science but also to fields such as exercise physiology, psychology, and performance optimization, offering practical applications for athletes and enthusiasts seeking to push the limits of human capabilities.

In sports, coaches and researchers aim to excel athletes by comparing and studying the best examples. Although we have a large scientific knowledge of the above-mentioned topics, we do not know from where these runners originate, from which nations the fastest 24-hour runners come, and where the fastest races are held. We know that specific nations and/or regions dominate specific ultramarathon race formats shorter than the 24-hour race[18,19]. In sports, coaches and researchers strive to elevate athletes by scrutinizing and learning from exemplary performances. Despite our extensive scientific knowledge on these subjects, there is a critical gap regarding the origins of top-performing 24-hour runners - information regarding the nations producing the fastest athletes and the locales hosting the fastest races remains elusive. While certain nations or regions dominate specific ultramarathon race formats shorter than the 24-hour duration, a comprehensive understanding of the 24-hour race landscape is yet to be attained. Closing this knowledge gap could provide valuable insight for optimizing athlete training and performance strategies in this challenging domain.

For example, 6-hour[20] and 12-hour[21] runners mainly originated from Europe. The data indicate that for races of specific durations, such as 6 and 12 h, the majority of runners originate from Europe. This phenomenon can be influenced by a combination of factors, including sporting culture, tradition, supporting infrastructure, investment in endurance sports, and regional training methods. However, 100-mile runners preferably competed in the USA, and US-Americans were also the fastest[22]. Additionally, identifying where the records come from allows researchers to argue the reasons for investment, staff, environmental conditions, and training methodologies.

Therefore, the objective of the present study was to investigate the origin of 24-hour ultramarathon runners and the fastest race locations. Based on existing findings that the fastest 6-hour and 12-hour ultramarathoners originate from Europe, we hypothesized that the fastest 24-hour runners would also originate from Europe.

Methods

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 in accordance with recognized ethical standards according to the Declaration of Helsinki adopted in 1964 and revised in 2013.

Data analysis

Data download

Race data was downloaded from the official website of Deutsche Ultramarathon Vereinigung - DUV (https://statistik.d-u-v.org) using a Python script (Python Software Foundation, USA). Each race record included the name of the runner, the age group and gender, the country of origin, the race location and year, the duration of the race, the performance (km) and the running speed (km/h).

Data pre-processing

The consistency of the data was checked, removing any incomplete or inadequate records. The countries of origin and event were then ranked by the number of race records, for which the dataset was aggregated by the values in the *athlete country column* (or *event country*) column, and then sorted by participation (number of records). In both cases, descriptive stats of running speed (mean, standard deviation, maximum and minimum values) and the number of unique runners are presented for each country.

To reduce noise and obtain representative results, race records from athlete countries with less than 10 records were removed, and similarly for event countries with less than 10 records. While these measures will allow for an easier interpretation of the results, we must acknowledge, however, that, in doing so, relevant results from some countries/runners may have been unwittingly omitted. In all cases, running speed descriptive stats (mean, standard deviation, maximum and minimum values) and the number of unique runners are also calculated for each country.

XG Boost regression model

The algorithm used is the popular XG Boost, in its regression flavor, trained with the full sample of 171,358 race records. The XGBoost algorithm is considered efficient for the detection of talent in sports, particularly in identifying outstanding runners in various endurance races such as 48, 24, and 12 hours. Its ability to handle complex and non-linear data, address imbalances in datasets, incorporate regularization techniques to prevent overfitting, evaluate feature importance, efficiently manage categorical variables, and deliver fast computational performance makes it a powerful tool for analyzing large datasets associated with athletes from different

nationalities and racing styles. XGBoost' s strengths lie in capturing intricate patterns and providing insights into the factors influencing performance, making it well-suited for talent identification and prediction in the context of diverse endurance running scenarios.

The following variables were used as predictors or inputs to the model: *Athlete_gender_ID*, *Age_group_ID*, *Athlete_country_ID*, and *Event_country_ID*. The predicted variable, or algorithm output, is the running speed (km/h). To train and evaluate the model, a holdout evaluation strategy was used, iteratively training, and evaluating different instances with different test splits and different number of estimators / learn rates. Two evaluation metrics Mean Square Error (MAE) and R^2 were calculated, achieving a best score (in-sample test) of $R^2 = 0.26$ (MAE of 1.36 km/h) with 500 estimators (learners or trees) and a learning rate of 0.4. The model features relative importances, and the partial dependence plots (PDP) and prediction distribution plots were also computed to help with the model interpretation. PDP plots show the relative amount of change on the model output for the different values of each predicting variable, with respect to a reference value (value 0), while prediction plots show the range of outputs for each predictor using a box.

Numerical encoding of categorical variables

Before the XG Boost model could be trained, the predictors' values had to be converted (encoded) into numerical data. The *athlete gender* variable is encoded as female = 0 and male = 1. The *age group* variable is already numerically encoded in 5-year groups (except group 18, which represents runners of less than 20 years, and group 75, which represents 75 years and older). The *athlete country* and *event country* variables are encoded based on their position in the respective rankings' tables, with the countries with the highest participation first.

Model interpretation

The model was then rebuilt with n_estimators = 500 and learn_rate = 0.4 and the model was trained and tested on the full sample. This 'optimal' model obtained an accuracy value of $R^2 = 0.25$, indicating a weak effect of the prediction variables on the model output, suggesting that additional prediction variables should be added to the model to improve its predictive power. All computation and analysis were done using a Jupter notebook (Google Colab) and Python and associated libraries (pandas, numpy, xgboost, pdpbox, sklearn, matplotlib, sns, etc.).

Results

After all necessary processing, the final 24-hour race sample consisted of 171,358 race records from 63,514 unique runners from 73 different countries participating in races held in 57 different countries.

Table 1 summarizes the race records by the 73 countries of origin of the athletes. Participation is spread across many countries (73 for the athlete´s country of origin), with the United States, France, Germany, UK, Italy, Japan, Russia, Australia, Austria, and Canada topping the ranking by number of race records. The fastest average running speed is achieved by Tunisian athletes (at more than 9 km/h, with 24 race records from three unique runners), followed at a distance by runners from Russia, Latvia, Lithuania, Island, Croatia, Slovenia, and Israel. The mean running speed is color-coded, with darker colors corresponding to higher values (i.e., faster running speeds).

Table 2 summarizes the events for 57 different countries. By event country, the ranking looks quite similar to participation by athlete (USA, France, Germany, UK, Italy, Japan, Russia, Australia, Austria, and Canada), which suggests a strong relationship between the country of origin and the country of event. The fastest 24 h races are recorded in Israel, Romania, Korea, the Netherlands, Russia, and Taiwan. The mean running speed is color-coded, with darker colors corresponding to higher values (i.e., faster running speeds).

XG Boost regression model

Optimal model evaluation metrics and features relative importance

The best model we could build (sample size 171,358, XGBoost trees 500) achieved only a score of MAE (km/h) 1.36) and $R^2 = 0.25$ which indicates a weak effect of the prediction variables in the model output, suggesting that additional prediction variables should be added to the model to improve its predictive power. The model (Fig. 1) rates the *country of the event* (0.54) as the most important predictor (based on data entropy reduction) with a score of 54% followed by *athlete country* (0.16), *age group* (0.15) and *sex* (0.14).

Partial dependence plots (PDP)

Regarding gender (Fig. 2), men were 0.4 km/h faster than women. The fastest running speeds were achieved by runners in the age groups 35–39, 40–44, and 45–49 years (Fig. 3). Outputs by athlete country reach their peak at ID 63 (Tunisia) (Fig. 4). The outputs by event country peak at IDs 34 and 35 (Romania and Korea) (Fig. 5).

Prediction distributions and target plots

The difference between the predictions of men and women is ~ 0.5 km/h on average (Fig. 6). The fastest runners are in age groups 40–44 and 45–49 years (Fig. 7). In the athlete country charts, a distinctive peak can be seen for Tunisia (Fig. 8). In the event country charts, Romania, Korea and Israel, Taiwan, the Netherlands, and Russia obtain the highest predictions (Fig. 9).

Discussion

In this study, we investigated both the origin of the fastest 24-hour runners and the location of the fastest 24-hour race courses. Based on existing findings that the fastest 6-hour and 12-hour ultramarathoners originated from Europe, we hypothesized that the fastest 24-hour runners would also originate from Europe. We found that the fastest 24-hour runners originated from Tunisia, followed mainly by several countries from Eastern Europe.

Athlete country		Running speed (km/h)				Race records	Unique runners
		Mean	Std	min	max		
0	USA	4.338	1.686	0.738	11.601	46998	20732
1	FRA	5.627	1.773	1.738	11.446	27698	9164
2	GER	5.002	1.996	1.875	11.509	21085	6398
3	GBR	5.406	1.980	1.875	11.437	8232	3947
4	ITA	5.468	1.807	1.875	12.018	6702	1929
5	JPN	6.031	2.004	1.875	11.890	4812	1742
6	RUS	6.652	2.042	1.875	11.762	4416	1137
7	AUS	5.966	1.816	1.875	12.646	4247	1320
8	AUT	5.715	1.744	1.877	11.143	3301	1096
9	CAN	5.072	1.636	1.875	10.712	3125	1173
10	SWE	5.618	1.957	1.885	11.108	2964	918
11	POL	5.703	2.183	1.914	12.577	2873	1307
12	BRA	5.382	1.604	1.877	11.409	2766	1125
13	ESP	5.188	1.949	1.875	11.431	2761	1209
14	CZE	6.267	1.807	1.883	11.130	2213	595
15	BEL	5.748	2.109	1.890	11.254	2200	729
16	HUN	6.362	1.885	1.776	11.562	1823	515
17	NOR	5.961	1.963	1.250	11.037	1794	601
18	NED	5.821	1.882	1.875	10.895	1770	522
19	DEN	5.746	1.813	1.903	10.740	1755	509
20	FIN	6.279	1.850	1.922	10.840	1726	502
21	TPE	6.160	1.740	1.961	10.201	1623	609
22	SUI	5.845	1.826	1.903	10.722	1210	355
23	ARG	5.895	1.474	1.956	9.961	1061	360
24	UKR	5.934	1.804	2.111	12.307	1049	300
25	GRE	5.574	1.919	1.911	11.936	1046	438
26	CHN	4.674	1.852	1.875	11.154	902	652

Table 1. Athlete country ranking.
Note: Std (standard deviation); Min (minimum value); Max (maximum value).

The model rated the country where the race was held as the most important predictor, followed by the origin of the athlete, age and gender. The athlete's origin is less important than the race location. Moreover, the model's prioritization of predictors underscores the significance of contextual factors in predicting athletic performance. In particular, the country hosting the race emerged as the most influential factor, suggesting that the geographical and environmental aspects associated with the race location play a pivotal role in shaping an athlete's performance.

This finding aligns with the understanding that climate, altitude, and terrain can significantly impact endurance sports. Although the origin of the athlete, encompassing factors such as cultural background and training methods holds importance, the model's ranking implies that the immediate race environment exerts a more pronounced influence on the outcome. This emphasis on location over athlete origin highlights the need for a nuanced approach in talent identification, where consideration of the specific conditions presented by the race venue becomes paramount. It also underscores the potential adaptability of athletes to diverse environments and the need for training strategies tailored to the unique challenges posed by different geographical settings.

The fastest 24-hour ultramarathoners originate from Tunisia

The fastest average running speed is achieved by Tunisian athletes (at more than 9 km/h, with 24 race records from three unique runners) followed at a distance by runners from Russia, Latvia, Lithuania, Island, Croatia, Slovenia, and Israel. We can, therefore, only partially confirm our hypothesis.

Athlete country		Running speed (km/h)				Race records	Unique runners
		Mean	Std	min	max		
27	IRL	6.404	1.975	1.978	10.784	819	283
28	MAS	4.168	1.162	1.917	7.961	705	366
29	IND	5.662	1.561	0.750	10.432	701	338
30	NZL	6.067	1.830	1.928	10.941	694	284
31	RSA	4.206	1.748	1.875	10.753	662	370
32	POR	4.660	1.944	1.875	9.857	576	357
33	SRB	5.659	1.600	1.875	10.778	539	150
34	BLR	6.061	1.695	1.925	10.625	376	78
35	SVK	6.432	2.101	1.883	11.264	373	75
36	EST	5.689	1.947	1.880	10.215	370	125
37	URU	5.634	1.461	2.130	9.441	358	126
38	ROU	6.205	1.891	1.917	11.562	318	153
39	KOR	6.136	1.996	1.917	10.050	292	136
40	LAT	6.749	2.047	2.083	10.785	260	94
41	MGL	5.183	1.647	1.875	9.870	230	115
42	HKG	6.441	1.709	1.943	9.800	193	89
43	LTU	6.781	2.035	2.097	13.317	155	32
44	PHI	5.295	1.551	1.983	9.087	142	98
45	MDA	5.042	1.709	1.956	9.439	133	64
46	SLO	6.661	2.247	1.884	11.040	124	51
47	ISR	7.241	1.596	2.500	9.560	114	33
48	CRO	6.861	1.949	2.200	10.645	108	52
49	MEX	5.638	1.725	2.069	9.464	108	58
50	BUL	6.208	1.805	2.500	10.546	104	28
51	LUX	4.956	1.533	1.913	9.074	96	47
52	CHI	5.329	1.360	1.883	8.665	82	47
53	TUR	5.420	2.071	1.875	9.632	63	32

Table 1. (continued)

We found in the PDP plots a distinctive peak for Tunisia, which could be confirmed with the prediction distributions and target plots value plots. However, this performance was achieved by three runners providing 24 race records. Tunisia has a few very successful elite ultramarathoners. For example, the best Tunisian 24-hour ultramarathoner, Mohamed Magroun, competed between 2001 and 2009 annually in 24-hour races and achieved between 204 and 257 km. Interestingly, Tunisia has no 24-hour runs, but rather desert ultramarathons such as the 'Ultra Mirage El Djerid' (www.ultramirage.com/), the 'Shitana Medium Trail (TUN)' (https://shitana.tn/), or the '100 km del Sahara' (www.100kmdelsahara.com/).

Most likely, ultramarathoners from Tunisia have a good preparation in ultramarathon running in the desert and need an alternative to the desert when running in a 24-hour run mainly held in short laps. This may also suggest that extreme environments play an important role in long-distance athletes. Similarly, the high performance of Tunisian athletes could be attributed to physiological and climatic conditions since most Tunisian middle- and long-distance runners come from rural western areas, particularly desert regions[23]. Additionally, it is possible that the increase in the number of international running events, for example, the 'Sfax Marathon' (www.sfaxmarathon.com/), the 'Ultra Mirage El Djerid' (www.ultramirage.com/), the 'Shitana Medium Trail (TUN)' (https://shitana.tn/) and the '100 km del Sahara' (www.100kmdelsahara.com/) followed by an increase in the number of participants in recent years may also explain our findings. However, more research is required to fully understand why Tunisian runners are the fastest in 24-hour ultramarathons.

The other countries with more runners appeared to have a considerably lower density in performance with more runners by country. From Russia, more than 3800 race results were recorded, where the best man achieved

Athlete country		Running speed (km/h)				Race records	Unique runners
		Mean	Std	min	max		
54	ALG	6.271	1.545	2.236	8.776	58	23
55	THA	4.363	1.109	2.123	6.950	56	49
56	BIH	5.742	1.843	1.896	9.222	53	14
57	KAZ	5.487	1.819	2.044	9.725	47	24
58	MKD	6.506	1.686	3.583	9.583	40	15
59	CYP	4.779	1.704	2.183	7.625	37	11
60	MNE	5.463	0.463	4.750	6.667	29	1
61	SGP	5.213	1.963	2.199	9.017	27	22
62	MAR	5.361	1.766	2.188	10.293	25	7
63	TUN	9.139	1.905	3.852	10.745	24	3
64	ISL	6.851	1.546	4.313	9.073	18	6
65	PAR	5.884	1.661	2.000	8.335	15	10
66	MON	4.127	1.211	2.272	5.831	15	8
67	INA	5.001	1.623	3.101	7.808	14	11
68	ECU	5.819	1.616	3.364	8.258	11	1
69	SOM	4.397	0.621	3.086	5.261	11	6
70	LBN	4.869	1.012	3.833	6.967	11	6
71	ALB	4.901	0.876	3.294	6.083	10	6
72	VEN	5.243	1.708	2.103	6.905	10	2

Table 1. (continued)

282 km and the slowest man 60 km. Regarding women, the best woman achieved 252 km and the slowest 60 km. Also, for Latvia, the best man achieved 258 km, the slowest 61 km. For women, the fastest woman arrived at 228 km, the slowest at 60 km. Considering Lithuania, the best runner arrived at 319 km, the slowest at 66 km. Also, for Israel, the best man arrived at more than 200 km with a 227 km race performance, the slowest only at 62 km. Obviously, the country's performance is determined by the weakest performance, not by the best performance. In general, the fastest 24-hour runners preferably originate from countries of Eastern Europe.

The fastest races

We found that the fastest running speeds were achieved in races held in Israel, Romania, South Korea, the Netherlands, Russia, and Taiwan. These countries are spread around the world. No specific trend for a defined ultramarathon running scene for 24-hour races could be found in the last decades. Most probably, all these fast races and/or countries show a very high density in performance regarding all finishers. Table 3 summarizes the most important 24-hour races by country for Israel, Romania, South Korea, the Netherlands, Russia, and Taiwan.

The running scene for 24-hour races is rather small in Israel, Romania, and South Korea. However, in South Korea, the World Championship in 24 hours was held in 2009. In the Netherlands, the first 24-hour run started in 1984 with the '24 uurs Apeldoorn' as a road race. It was held until 2007. In addition, several European and World Championships were held in the Netherlands since 2000. These Championships, where the best athletes from a continent or the world compete, may explain why fast races were held in the Netherlands. Russia and Taiwan have both a long tradition of 24-hour running. In Russia, the first race started in 1979 with '24 hours Nytva'. The '24 h Sutki Begom' Moskau was started in 1983 and is held as a track race. In Taiwan, several races with a long tradition were held as track runs. And some races were held as Championships. In the' Taipei 48-hour Ultra Marathon', a 24-hour split was regularly recorded (https://iau-ultramarathon.org/events-results.html). Obviously, the reason for the fast races in Taiwan were track races and Championships.

In general, fast races with high running speeds and many kilometers are most likely due to Championships. That said, it is important to note that in some cases, the organization of big international events in a specific country may result in better results.

Race locations

We also found that the USA, France, Germany, the UK, and Italy were the first five countries by number of participations (race records) and accounted for nearly 70% of the sample. Table 4 summarizes the most important events for USA, France, Germany, the UK, and Italy.

Event country		Race speed (km/h)				Race records	Unique runners
		Mean	Std	min	Max		
0	USA	4.344	1.674	0.738	11.936	47903	21377
1	FRA	5.759	1.799	1.738	11.890	28654	10246
2	GER	4.715	1.896	1.875	11.509	17699	6478
3	GBR	5.411	1.992	1.875	11.437	8294	4618
4	ITA	5.723	1.959	1.875	13.317	7171	2638
5	AUS	5.884	1.768	1.875	12.646	4238	1486
6	JPN	5.721	1.865	1.875	11.218	4184	1725
7	AUT	5.887	1.818	1.877	11.169	3993	1670
8	NED	6.593	1.993	1.875	11.254	3924	1573
9	RUS	6.561	2.004	1.875	11.762	3821	1129
10	SUI	6.129	1.832	1.878	12.093	3397	1498
11	POL	5.770	2.220	1.914	12.892	2938	1545
12	ESP	5.211	1.955	1.875	11.240	2921	1575
13	CAN	5.172	1.710	1.875	10.982	2761	1322
14	BRA	5.313	1.554	1.877	11.258	2586	1120
15	CZE	6.283	1.817	1.883	11.212	2401	1020
16	TPE	6.599	1.920	1.961	11.890	2189	960
17	NOR	5.884	1.875	1.250	11.037	2112	929
18	SWE	5.301	1.860	1.907	11.108	2084	925
19	FIN	5.966	1.765	1.885	10.840	1872	844
20	HUN	5.952	1.786	1.776	11.562	1755	742
21	BEL	5.243	2.109	1.890	11.010	1668	874
22	DEN	5.618	1.685	1.903	11.056	1416	610
23	GRE	5.563	1.739	1.875	10.854	1337	728
24	ARG	5.715	1.399	2.000	10.000	1058	647

Table 2. Event country ranking.
Note: Std (standard deviation); min (minimum value); max (maximum value).

The USA have a long tradition of 24-hour races, with the first race in 1879 where the 'Int. The Astley Belt Long Distance Championship' recorded a 24-hour split time. Since the eighties, the number of 24-hour races has continuously increased. Over time, 24-hour races were expanded to include a 48-hour, a 72-hour, and a 6-day race, such as the 'Gibson Ranch 6-Day Classic'. In recent years, the event 'Across the Years' has offered all races from 6 hours to 6 days (www.aravaiparunning.com/across-the-years/). Other races, such as the 6 days and 10 days in New York, record a 24-hour split time (https://us.srichinmoyraces.org/events/6-10-day-race). The combination of a long tradition, many single 24-hour races, and ultra-running festivals, including 24-hour races, may have led to the high number of these races in the USA.

Also, France has a long tradition in 24-hour races, with its first race in 1892 with the '24 Heures de Neuilly' held as a track race. In the 1970s, 24-hour races also started regularly in France. Similar to the USA, 24-hour split times were recorded in longer races such as the 'Les Six Jours de La Rochelle' or the '48 heures pédestres de Surgères' (www.marathons.fr/Calendrier-des-24-heures-de-France).

Germany has a short tradition in 24-hour running, with the first race, the '24 Stundenlauf Mörlenbach', held in 1980. During the 1980s and 1990s, only a few races were held annually. In the 21st century, National Championships were regularly held. Interestingly, in Germany, no running festivals were held where the 24 h would be part of the event. And no Continental or World Championships were held (www.runnersworld.de/laufevents/ultralauf/).

The UK's first 24-hour run was held in 1807 as the '24 h Newmarket'. Until 1900, nearly ten 24-hour races were recorded. In the late 1970s, the number of 24-hour races slowly increased. Most were single 24-hour races

Event country		Race speed (km/h)				Race records	Unique runners
		Mean	Std	min	Max		
51	LAT	5.600	2.396	2.083	10.785	20	19
52	ALG	5.238	1.113	2.583	7.042	20	18
53	MEX	4.752	1.650	2.357	7.937	17	15
54	UAE	5.082	1.485	2.167	7.604	17	17
55	BLR	4.999	1.762	1.925	7.747	16	15
56	SLO	6.267	2.331	3.250	10.714	13	13

Table 2. (continued)

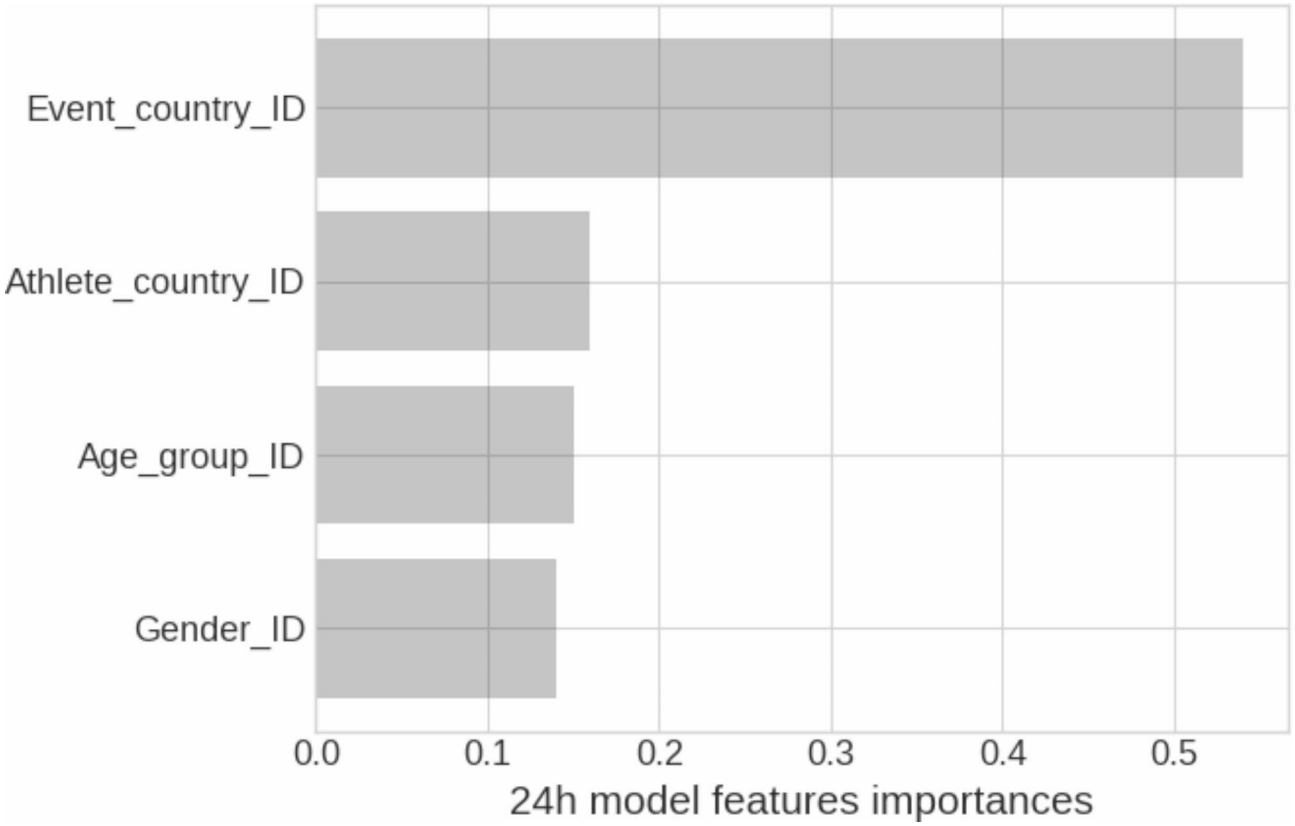

Fig. 1. Optimal model evaluation metrics and features importance.

held as road, track or trail runs with no running festivals (www.runningcalendar.co.uk/calendar/running/ultramarathons/). Only one Championship was recorded where in 2017 the 'IAU 24 h WC Belfast' was held.

Italy started very early with 24-hour runs with '24 ore Roma' held in 1879. A new start at the beginning of the 1970s with several track races such as the '24 ore pista Brescia', the '24 ore di Bergamo su pista', the '24 ore su pista di Saronno', the '24 ore su pista di Pordenone' and others were only very few runners started. At the beginning of the 1980s, regular 24-hour runs began, with the '24 ore di Gonars' being the first. In the 1980s and 1990s, only a few races were held annually. In last two decades, several Championships were held (Table 4).

This allows us to argue that the experience of organizing 24-hour running events may contribute to the records. In these countries, the events may have more popularity and adherence. Again, Championships and track races dominate.

Men were faster than women

Overall, men ran 0.4 km/h faster than women. It is well known that men are faster than women in ultra-endurance running[14] which might be due to physiological[24] or participation[25] reasons. However, women

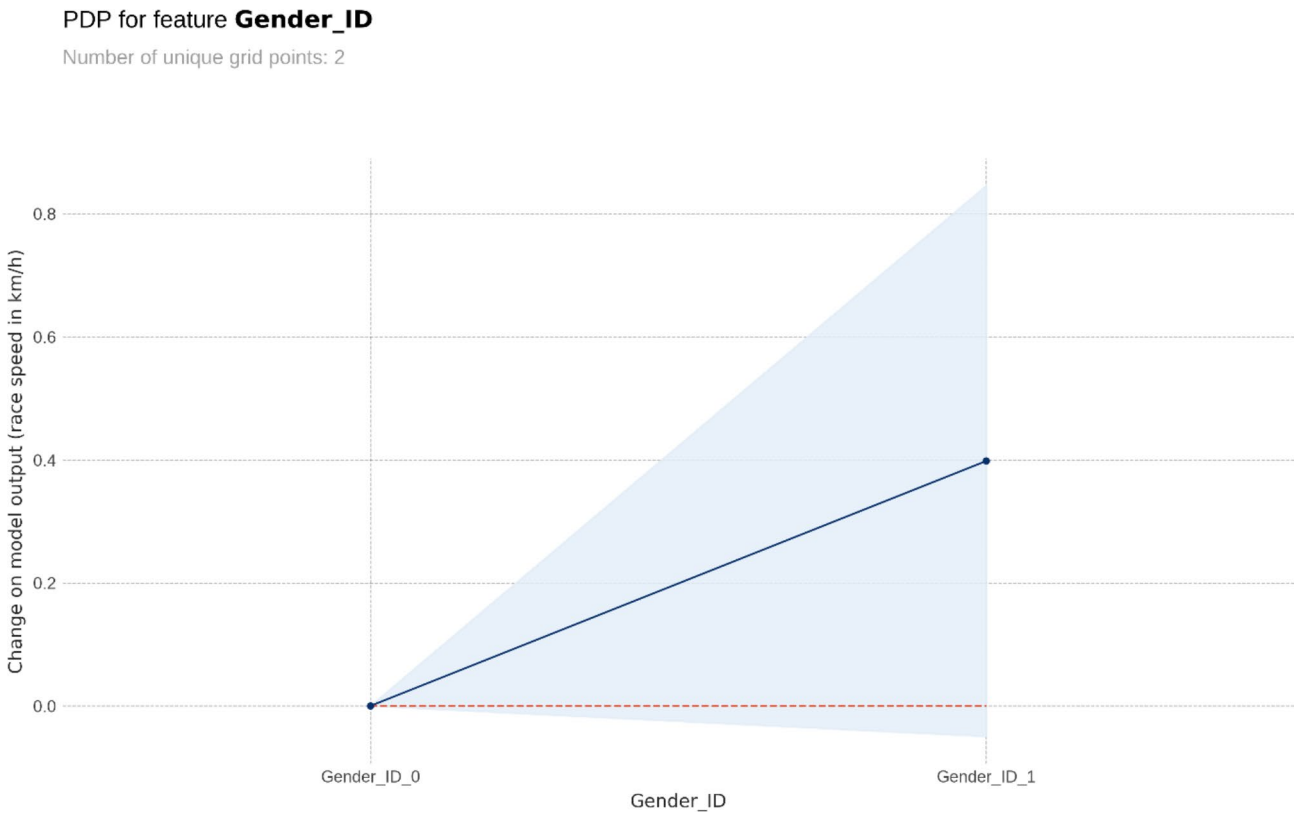

Fig. 2. Partial dependence plots (PDP) for gender.

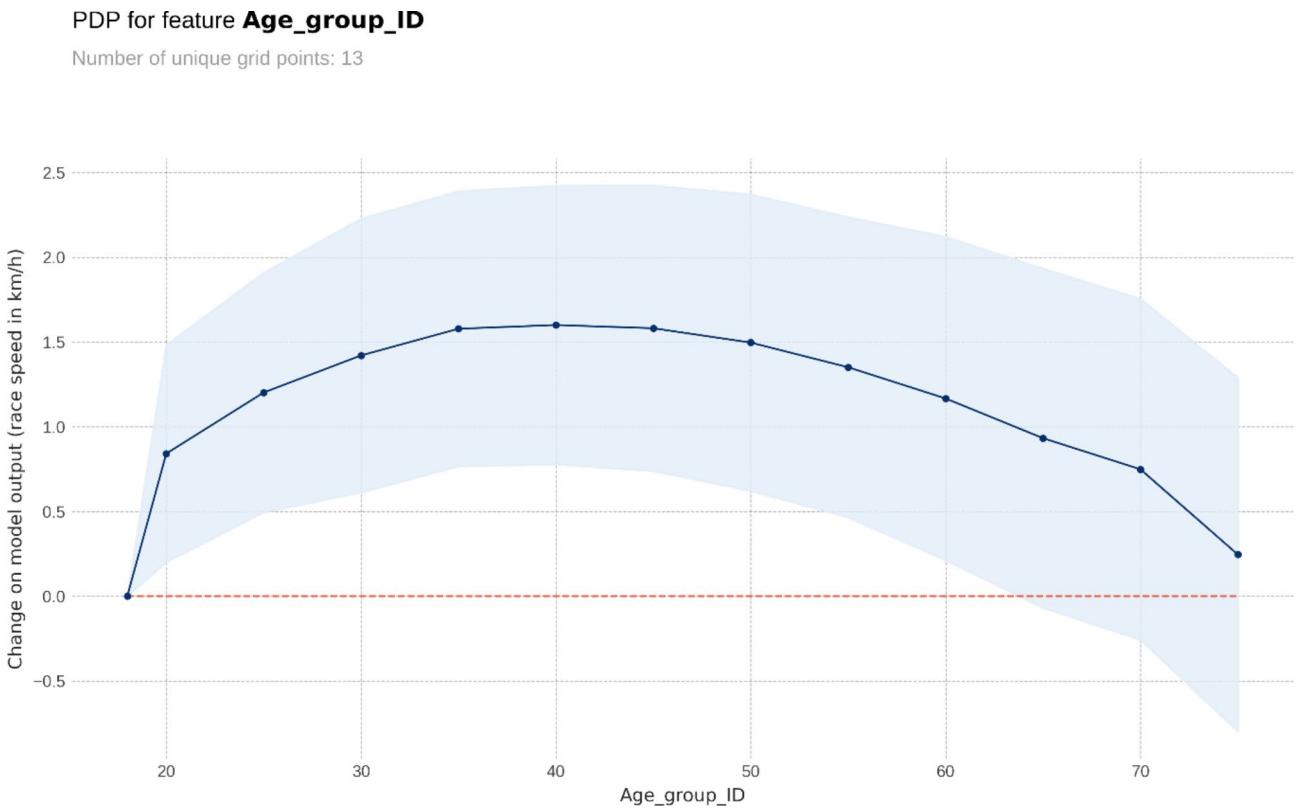

Fig. 3. Partial dependence plots (PDP) for age group.

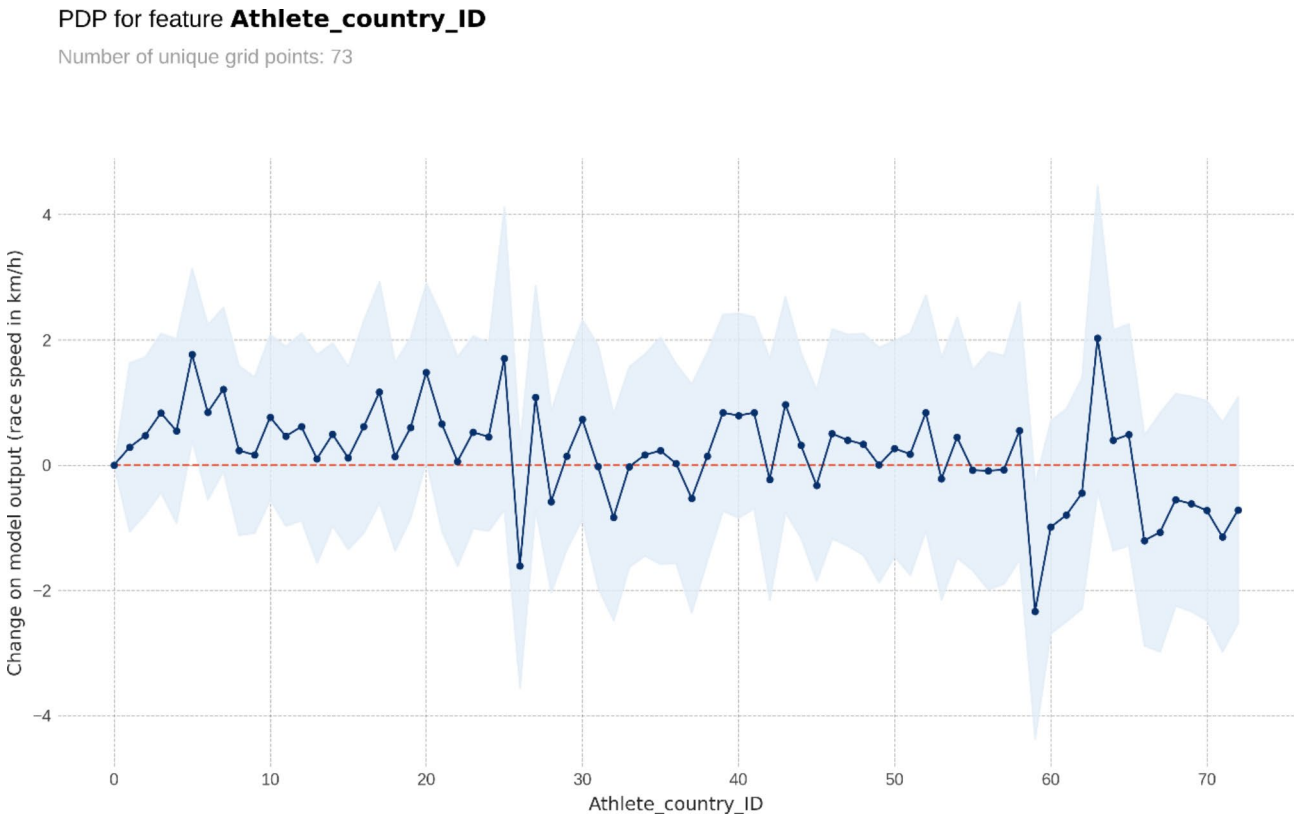

Fig. 4. Partial dependence plots (PDP) for the country of origin of the athlete.

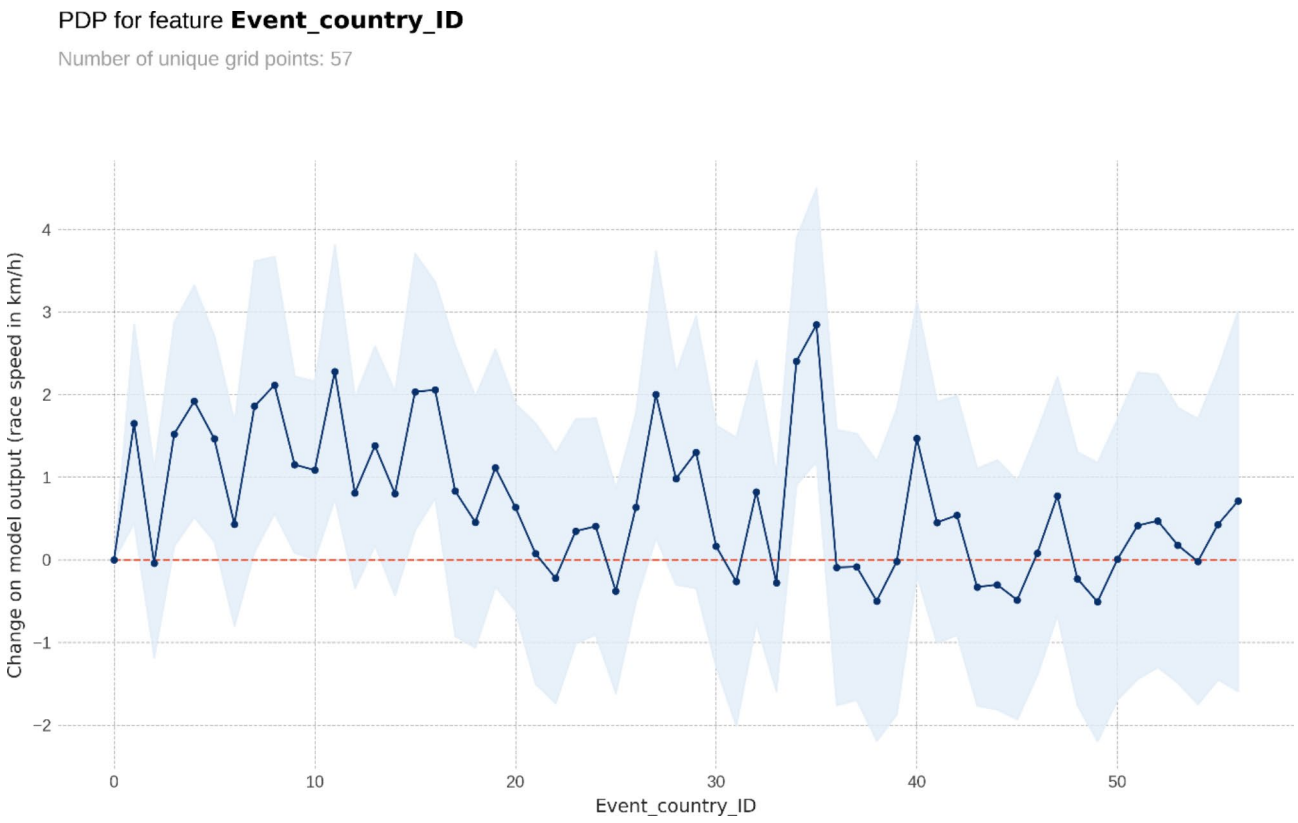

Fig. 5. Partial dependence plots (PDP) for the country of the country where the race was held.

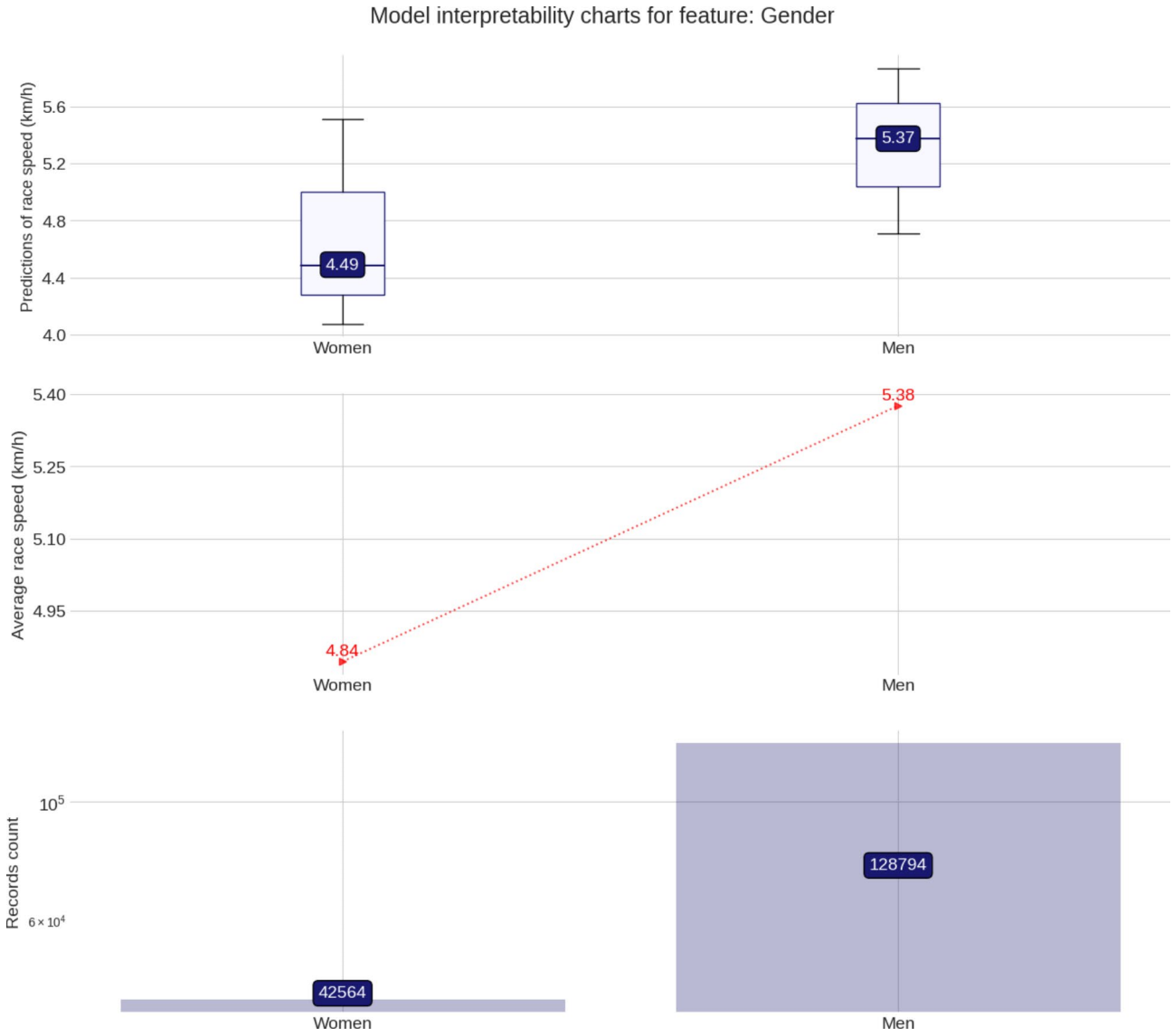

Fig. 6. Prediction distributions and target value plots for gender.

appeared to reduce the gap between men and women in ultramarathon running with increasing age[26,27], but not with increasing duration of a time-limited ultramarathon[28]. Regarding the 24-hour race format, the sex difference decreased in the last decades[14] where women were even able to outperform men in three years (1986, 2003 and 2006)[2]. Obviously, although men were faster than women, they seem to close the gap to men, especially with increasing length of the ultramarathon and with increasing age of the athlete.

Performance differences between men and women in ultra-endurance running events can be attributed to a combination of biological, physiological, and anatomical factors[29]. There are several key factors, such as strength and muscle mass, cardiovascular system, hormonal differences, metabolism, and pacing, which contribute to men generally being faster than women in ultra-endurance running. On average, men tend to have greater muscle mass and physical strength compared to women[30,31]. Men generally have larger hearts and lungs, resulting in a higher oxygen transport capacity, improved cardiovascular efficiency and then better endurance performance[32,33]. Hormonal variations, particularly higher levels of testosterone in men, can influence muscle development, recovery, and overall athletic performance[34,35]. Men often have a higher basal metabolic rate[36]. This can affect energy utilization during endurance events[37]. Pacing can significantly impact performance in ultra-endurance events where men and women adopt different pacing strategies during races[38,39]. Women generally have a higher percentage of body fat, which can affect heat dissipation and thermal regulation during prolonged exercise[40,41].

The age of peak running performance

We found that the fastest running speeds were achieved by runners in age groups 35–39, 40–44, and 45–49 years. This confirms recent findings that 24-hour ultramarathoners were the fastest when they were older than 35

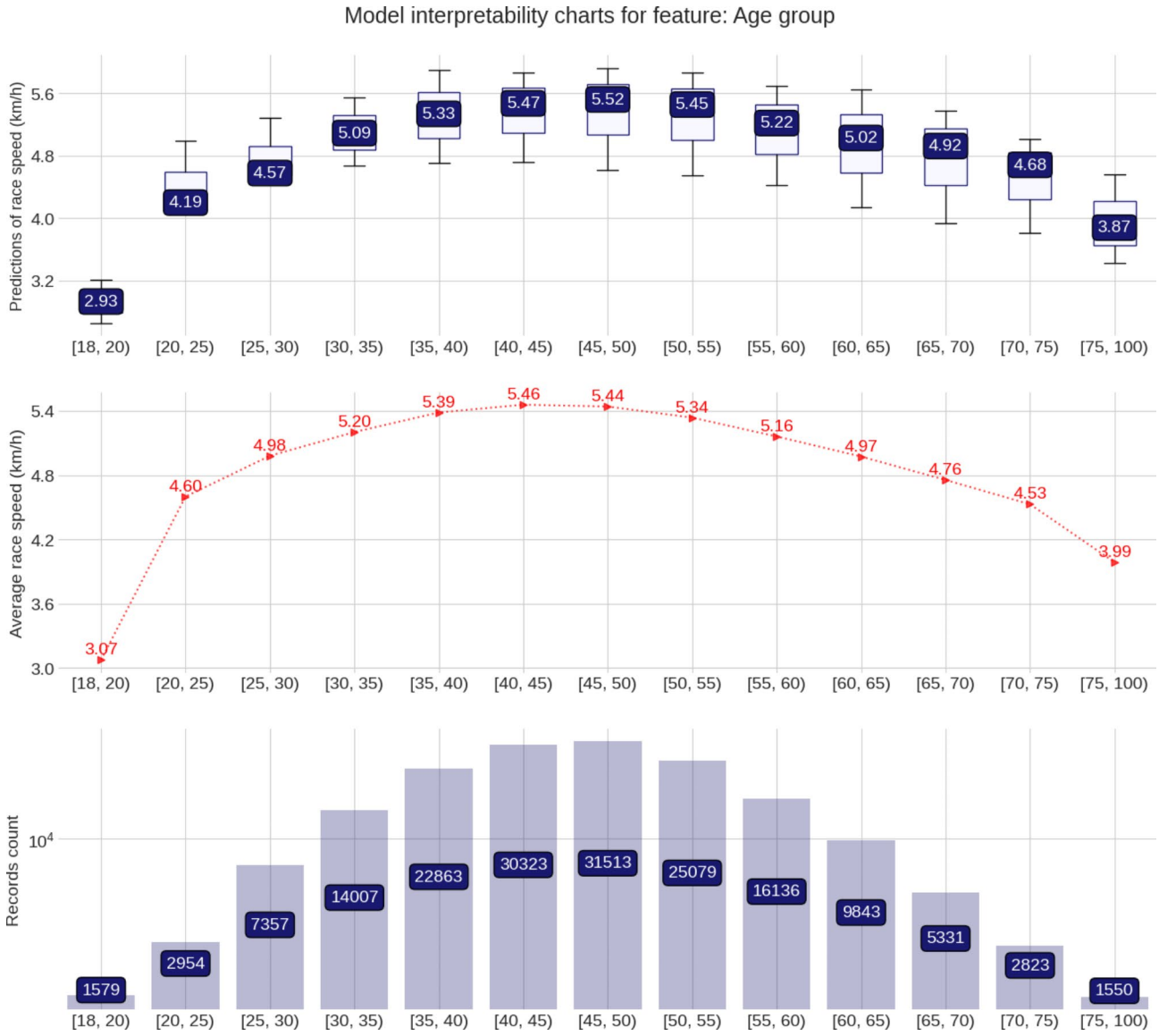

Fig. 7. Prediction distributions and target value plots for age group.

years[14], and particularly 40–45 years old[14]. Interestingly, the age of peak performance in 24-hour run increased across calendar years[13], which might reflect the entry of 'new' runners of relatively advanced age. Overall, 24-hour ultramarathoners belong to the master category. Moreover, this finding of the present study about the age of peak performance had perspective not only for sport performance, but also health[42]. Master athletes have been recently examined in the scientific literature as a model of successful aging[43]. Consequently, the achievement of peak performance in 24-hour run even in the fifth decade of human life could be viewed as a promising discovery about the contribution of exercise on the attenuation of the age-related decline[44].

Limitations

We limited the analysis to countries with at least 10 athletes recorded, indicating a commitment to a minimum inclusion threshold. This criterion probably aimed to ensure a certain level of representativeness for each country in the analysis. However, the acknowledgment that not all race records were complete with athletes' names or ages raises a potential limitation. The necessity to exclude some race results due to incomplete data could have led to the exclusion of a substantial sample of athletes, possibly introducing bias into the analysis. Despite this limitation, a notable strength of the study is its inclusion of athletes spanning from the 19th century. Since not all race records were complete with the athlete's first name, last name, or age, we also had to exclude a part of the race results. These steps might have led to the exclusion of a considerable sample of athletes. However, strength of this study is that we considered all other recorded athletes, with the first athletes competing in the 19th century.

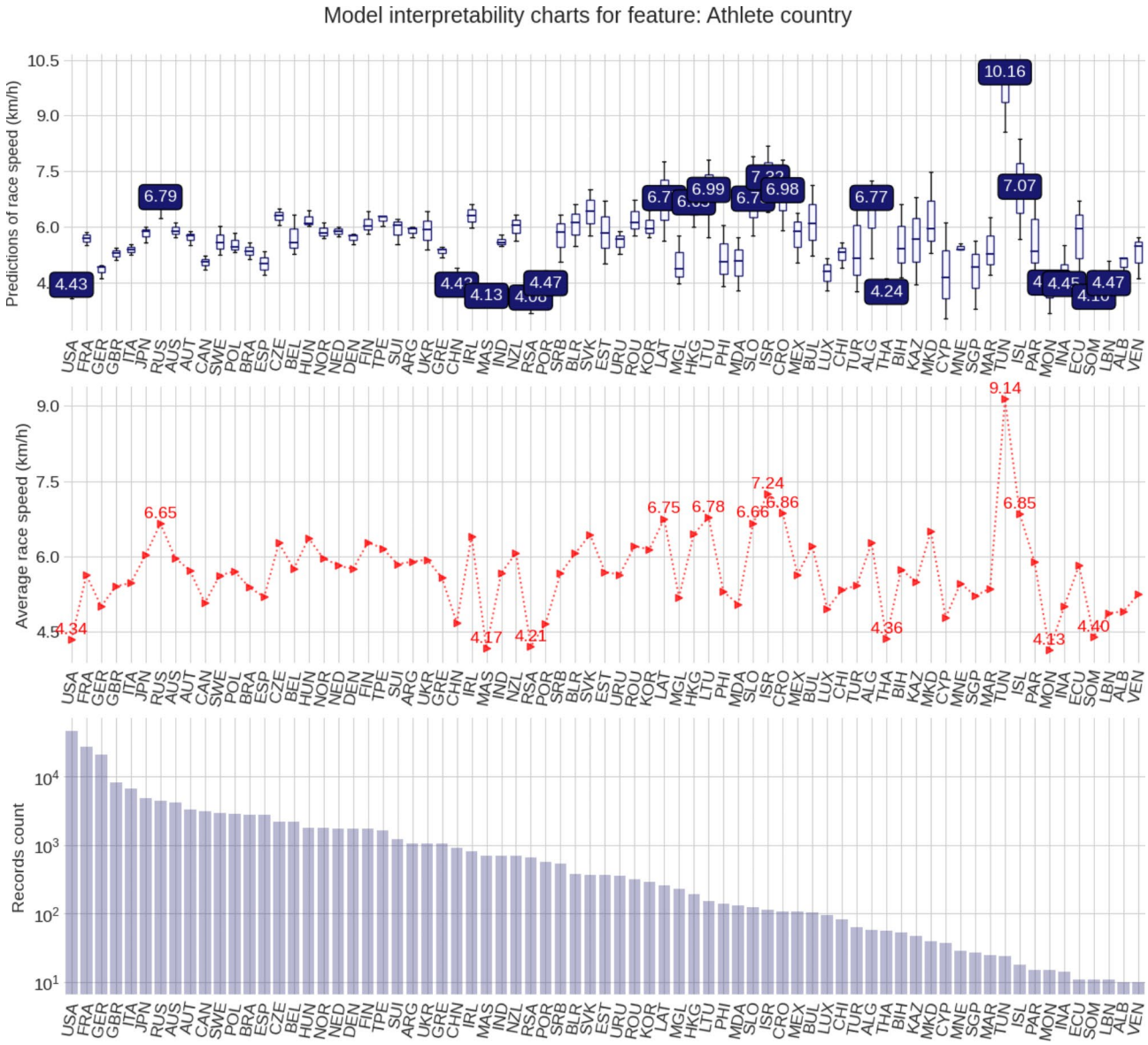

Fig. 8. Prediction distributions and target value plots for the athlete´s country of origin.

Conclusions

In summary, the highest numbers of 24-hour ultramarathoners originate from the USA, France, Germany, the UK, and Italy. The high number of 24-hour events was generally due to a combination of a long tradition, an increasing number of single 24-hour races and running festivals with all race formats from 6 h to 6 days. The fastest 24-hour runners mainly came from countries of Eastern Europe such as Russia, Latvia, Lithuania, Croatia, and Slovenia. The fastest running speeds were achieved in races held in Israel, Romania, Korea, the Netherlands, Russia, and Taiwan. This was mainly due to races held as track races and Championships at different levels.

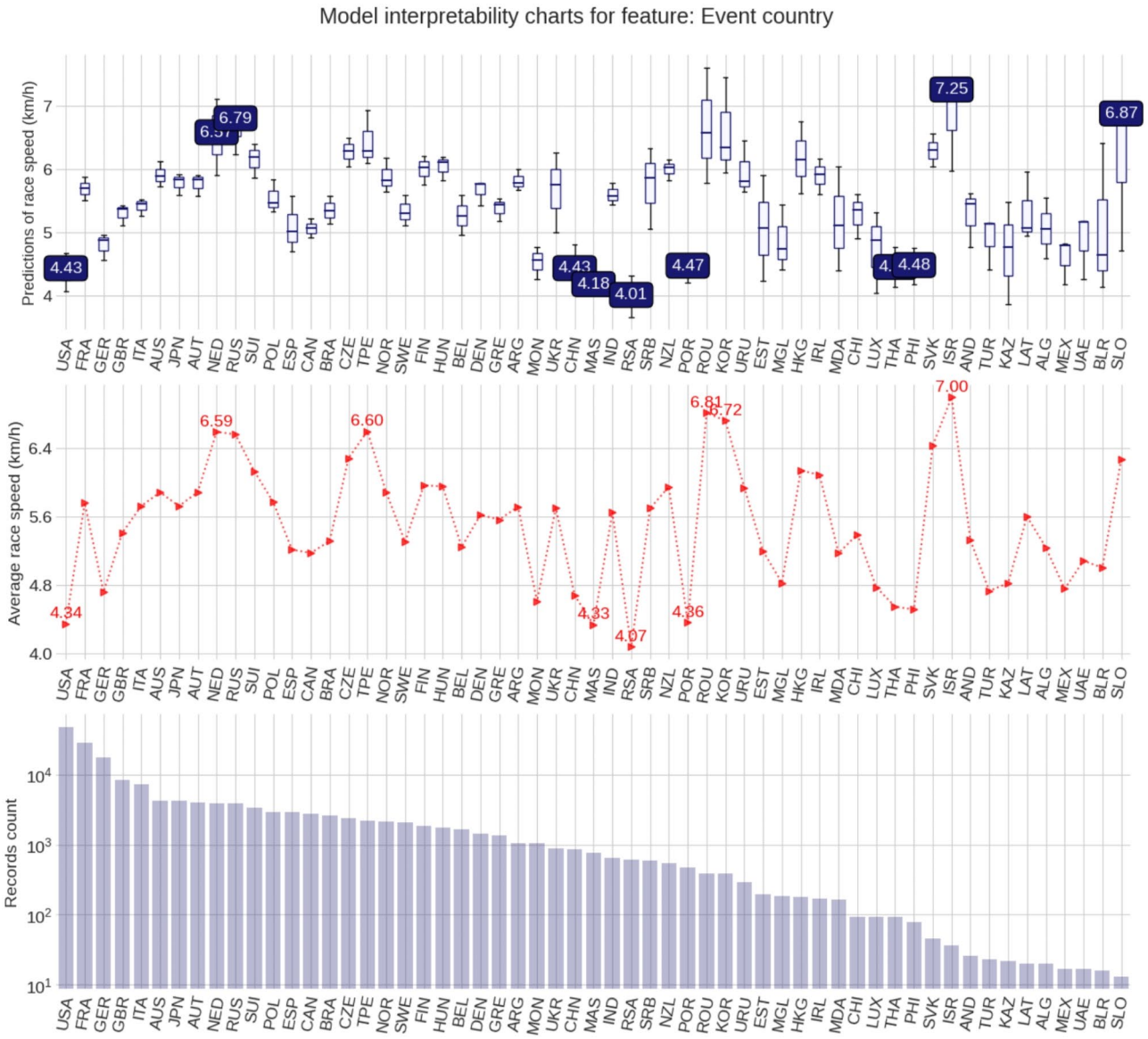

Fig. 9. Prediction distributions and target value plots for the country where the events were held.

Country	Event	Timeframe
Israel	Spartanion 24 h race	Start in 2020
Romania	S24H Timisoara	Start in 2016
South Korea	Korea 24 h Race	2002–2006 as track race
	IAU 24 h WC Seoul	2009
	KUMF 24 h Cup	2005
Netherlands	24 uurs Apeldoorn	1984–2007
	7th IAU 24 h EC Uden	2000
	8th IAU 24 h EC Apeldoorn	2001
	IAU 24 h WC Uden	2003
	IAU 24 h EC Steenbergen	2013
	IAU 24 h WC Steenbergen	2013
Russia	24 h Nytva	Start in 1979
	24 h Sutki Begom Moskau	Start in 1983 as track race
	Ispitai Sebia Ultramarathon, 24 h St. Petersburg	1988–2010
	Moscow Self-Transcendence 24 h race	Start in 2014
	24-hour self-transcendence race Moscow	2018–2021
Taiwan	Soochow / Taipei 24 h ultramarathon	Since 1999 as track race
	IAU 24 h WC Taipei Yuanshan	2006
	Taipei 24 h Ultra Marathon	Start in 2012
	Kaohsiung 24 h Track Ultramarathon	2015–2019 as track race
	24 h Asia and Oceania IAU Championship	2016
	24 h Asia and Oceania IAU Championship	2018

Table 3. 24-hour races by country of location.

Country	Event	Time frame
USA	Int. The Astley Belt Long Distance Championship	1879
	New York 6-day race, 24-hour split times	1882, indoor track run
	24-hour track race Glassboro	Start in 1970 as track run
	Miami Runners 24 h Track Run	Start in 1970 as track run
France	24 Heures de Neuilly	Start in 1892 as track run
	Les 24 heures du Mans	Start in the Seventies
	24 heures de Cotquidan	Start in the Seventies
	24 heures de Niort	Start in the Seventies
Germany	24 h in Stadtoldendorf'	2009 National Championship
	24 h in Stadtoldendorf'	2012 National Championship
	24-Stundenlauf in Reichenbach	2011 National Championship
	24-Stundenlauf in Reichenbach	2015 National Championship
	24 h von Gotha	2017 National Championship
	Bottroper Ultralauf Festival 24 h	2019 National Championship
UK	IAU 24 h WC Belfast	2017 World Championship
Italy	IAU 24 h EC Verona	1999 European Championship
	24 h WC Verona	2001 World Championship
	IAU 24 h EC Verona	2006 European Championship
	IAU 24 h WC Bergamo	2009 World Championship

Table 4. 24-Hour races by country.

Data availability

Availability of Data and Materials For this study, we have included official results and split times from the official website (https://statistik.d-u-v.org). The data sets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

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Author contributions

Conceptualization: B.K. Data curation: B.K. and E.V. Formal analysis: D.V. Methodology: B.K. and E.V. Writing – original draft: B.K., M.T., V.S., K.W., P.F., R.L.V., C.A.B.de L., P.N., N.O. and T.R.

Declarations

Competing interests

The authors declare no competing interests.

Ethics 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 in accordance with recognized ethical standards according to the Declaration of Helsinki adopted in 1964 and revised in 2013.

Additional information

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