

The influence of course characteristics on the variability of finishing times and running speed in forest individual races at the World Orienteering Championships from 2009 to 2019

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Abstract:

Problem Statement and Approach: A successful foot orienteering performance has been described as a combination of high endurance and cognitive capabilities, with elite orienteers demonstrating a high ability to run on physically demanding terrain. The uniqueness of length and type of terrain of each orienteering race led us to investigate the influence of course characteristics, such as length, distance climbed, number of control points, course technical difficulty, terrain morphology, runnability, and visibility, on finishing times and running speed in World Orienteering Championship (WOC) Forest competitions. **Material and Methods:** The official WOC results from 2009 to 2019 were collected and complemented with qualitative course characteristics. We used the Pearson product-moment correlation to analyze the relation between course characteristics, such as length, distance climbed, number of control points, course technical difficulty, terrain morphology, runnability, visibility, and performance indicators of finishing time and running speed. **Results:** Similarities between sex differences were found in long-distance races ($22\% \pm 3\%$) and in middle-distance races ($22\% \pm 4\%$), with female orienteers showing a higher interquartile range within the top 30 best-ranked athletes at the WOC races. When we applied a normalization to race length, this variable showed a very large positive correlation with middle-distance finishing times. Running speed showed a very large positive correlation with course length and a large to very large negative correlation course technical difficulty. For male long-distance races, higher differences between athletes were found on courses with a low number of CP, low visibility, and heavier terrain. **Discussion:** These greater sex differences found for the individual forest orienteering disciplines may be due to the terrain type encountered during competition and by the navigational tasks. The true nature of forest orienteering, where terrain type influences the physiological performance of athletes, explains the large to very large effect that course characteristics have on running speed for both disciplines and sexes. **Conclusions:** Our results suggest that orienteering course setters should pay careful attention to balancing length and technical difficulty of the orienteering courses with terrain type, as we observed a very large relation between course characteristics and running speed on WOC races. To increase the difficulty of the navigational tasks, they should seek competition terrains with low visibility terrain and reduced runnability and prepare courses with a low number of control points. Moreover, sex differences in orienteering performance are higher than in other endurance sports.

Key Words: foot orienteering, performance, off-road running, sex differences, statistics

Introduction

Orienteering is a rather complex sport that combines running and navigation. The sport is performed in mostly off-trail and hilly terrain, normally forest or mountain, with athletes completing their courses in the shortest possible time by visiting a sequenced number of control points (CP) and while using only a map and a compass to find their way through the forest (International Orienteering Federation, 2020).

A successful foot orienteering performance relies on the combination of a high endurance capability (Gjerset, Johansen, & Moser, 1997; Larsson, Burlin, Jakobsson, & Henriksson-Larsén, 2002; Moser, Gjerset, Johansen, & Vadder, 1995; Smekal et al., 2003), with elite orienteers demonstrating high ability to run on physically demanding terrain (Jensen, Franch, Kärkkäinen, & Madsen, 1994; Jensen, Johansen, & Kärkkäinen, 1999) and steep inclines (Lauenstein, Wehrlein, & Marti, 2013) with a skilled map-reading ability (Guzmán Luján, Pablos, & Pablos, 2008; Millet, Divert, Banizette, & Morin, 2010). Elite orienteers are faster and better decisions makers (Eccles, Walsh, & Ingledew, 2002a; Oliveira & Araújo, 2005) and have better visual attention (Eccles, Walsh, & Ingledew, 2006), enabling them to find the best routes between control points. They normally perform three to seven technical trainings a month to improve their navigational skills (Sirakov & Belomazheva-Dimitrova, 2018), with this systematic training program producing improvements on the athletes' mental qualities (Belomazheva-dimitrova & Sirakov, 2021).

Until 2019, the forest individual races of the World Orienteering Championships (WOC) were held

yearly, including two distances: middle distance and long distance. There are no fixed distances for the courses of each discipline, and the rules mention that winners' times should be between 30 and 35 min for middle distance and between 70 and 100 min for long distance (International Orienteering Federation, 2020). Because the venue of the championships varies, the type of terrain also changes. This means that, over the years, courses for the same discipline have had a wide range of distances, translating to different winning times. Unexpectedly, over the years, a 20% increase in the distance of the middle-distance course has led to a moderated reduction in winner times (Kim Hébert-Losier, Platt, & Hopkins, 2015).

The uniqueness in length and type of terrain of each orienteering race led us to this investigation. The question we had is: how do course characteristics influence both the finishing time and the running speed in WOC forest individual races? Some of the characteristics are well documented, such as length, number of controls, and distance climbed, but characteristics concerning the course technical difficulty and terrain type, such morphology, runnability and visibility, are not. To our knowledge, our study is the first that has attempted to access this qualitative data regarding WOC course characteristics.

The aim of this study was to evaluate the association between course characteristics, finishing time, and running speed on the forest individual races of the WOCs, regarding winner and the variability of the top 30 ranked athletes. This will allow coaches and course setters to have better insight on what factors influence the athletes' performances on forest orienteering races, permitting then to develop courses that meet the International Orienteering Federation competitions rules (International Orienteering Federation, 2020).

Materials & methods

Data collection. The official WOC results from 2009 to 2019 were obtained using the International Orienteering Federation's database. When the results were not available there, the organizing committees were contacted to collect the necessary data. We collected official finishing times, split times for each leg, ranks of each athlete, and course characteristics, including length of the course, climb, and number of CP. To normalize course length, an equivalent factor (EF) of 6.2 for men and 6.4 for women was applied using the formula $E\text{Fracelength (km)} = \text{race length} + (\text{climb} \times \text{EF})$, as described in Lauenstein et al. (2013). Table 1 summarizes the collected data.

Data were collected for the two individual forest foot orienteering disciplines: middle and long distance. Data were collected from 2009 to 2019. Because rules changed regarding number of runners in the finals, mainly due to a rule change regarding qualifying round, to obtain consistent data, only the top 30 results were considered for our study.

Written informed consent from individuals was not sought because no individuals were named, and the data from official results used in this project were in the public domain.

Qualitative course characteristics evaluation. To characterize course technical difficulty and terrain type, a questionnaire was developed in collaboration with an international high-level national team coach. To obtain consistent data, questionnaires were sent to all athletes that had three or more top 30 results within the time frame of our study. The individually made questionnaires inquired athletes about course technical difficulty, from 1 (very easy) to 10 (very hard), terrain morphology, from 1 (very low climbing) to 10 (very high climbing), terrain runnability, from 1 (very easy) to 10 (very hard), and terrain visibility, from 1 (very low) to 10 (very high). An informed consent was present at the beginning of each questionnaire.

Statistical analysis. All data were compiled for analysis using Excel for Office 365 (Microsoft Corporation, Redmond, WA) and statistically analyzed using SPSS 26.0 (SPSS, Chicago, IL, USA). Tables with descriptive summaries of the data are presented using mean, SD, and range values.

Data were screened for normality of distribution and homogeneity of variance using a Shapiro-Wilk normality test. When these assumptions were not met, the data were log-transformed before analysis to limit bias arising from nonuniformity of error (Hopkins, Marshall, Batterham, & Hanin, 2009).

Finishing times, running speed, and course characteristics for the females and males were compared using an independent samples t-test. To calculate the running speed ratio between male and female athletes, we applied the formula: $\text{running speed ratio} = \text{male speed} / \text{female speed}$.

Analysis of association between finishing times and running speed with course characteristics was performed using a Pearson product-moment correlation with the bias-corrected and accelerated bootstrap (BCa) confidence intervals set at 95%. Magnitudes of correlations were interpreted using thresholds of 0.1, 0.3, 0.5, and 0.7 for small, moderate, large, and very large correlations, respectively (Hopkins et al., 2009). Statistical significance was set at $P < 0.05$.

Results

Within the analyzed years, 319 different athletes obtained a top 30 classification in at least one individual WOC forest race, resulting from 660 individual races. From those athletes, 129 obtained at least three top 30 classifications.

A qualitative course characteristics evaluation questionnaire was sent to all 129 athletes with at least three top 30 classifications within the studied years. The answer rate was 88% for male disciplines and 86% for female disciplines.

Course characteristics. The list of course characteristics is summarized on Table 1. In middle-distance races, female course characteristics were significantly different in length ($-22\% \pm 8\%$), climbing ($-23\% \pm 10\%$), and number of control points ($-18\% \pm 6\%$) compared with the male courses. In long-distance races, the winning time for female athletes was shorter than for male athletes (70 to 80 min vs. 90 to 100 min), so a comparison between classes was not possible. No differences between male and female athletes were found regarding the qualitative data of the courses.

Table 1: Course characteristics (mean $\pm$ SD) of the forest individual races of the World Orienteering Championships from 2009 to 2019. To minimize the climbing effect, we applied an equivalent factor (EF) to normalize race length (Lauenstein et al., 2013).

	Middle distance			Long distance		
	Female	Male	<i>p</i>	Female	Male	<i>p</i>
Race length (km)	5.0 $\pm$ 0.5	6.1 $\pm$ 0.4	<0.01	11.2 $\pm$ 1.2	16.7 $\pm$ 1.3	-
<i>min - max</i>	3.8 - 5.5	5.4 - 6.6		9.7 - 13.4	15.1 - 19.5	
Distance climbed (m)	210 $\pm$ 27	256 $\pm$ 31	<0.01	434 $\pm$ 91	635 $\pm$ 142	-
<i>min - max</i>	170 - 260	225 - 315		255 - 540	345 - 820	
No. control points	18.5 $\pm$ 2.5	21.8 $\pm$ 2.6	<0.01	21.4 $\pm$ 2.7	29.5 $\pm$ 3.2	-
<i>min - max</i>	15 - 22	19 - 25		18 - 27	24 - 33	
EF race length (km)	6.3 $\pm$ 0.4	7.6 $\pm$ 0.4	<0.01	13.9 $\pm$ 1.1	20.6 $\pm$ 1.4	-
<i>min - max</i>	5.5 - 6.9	6.9 - 8.3		12.5 - 16.2	19.2 - 23.7	
Technical Difficulty	7.2 $\pm$ 1.2	6.9 $\pm$ 1.3	ns	6.7 $\pm$ 1.2	6.7 $\pm$ 1.2	ns
<i>min - max</i>	4.5 - 9.5	4.6 - 9.1		4.8 - 9.4	5.0 - 9.3	
Terrain Morphology	6.2 $\pm$ 0.6	6.3 $\pm$ 1.0	ns	6.3 $\pm$ 1.4	6.2 $\pm$ 1.6	ns
<i>min - max</i>	5.4 - 7.1	4.4 - 7.6		4.5 - 8.1	3.9 - 8.2	
Terrain Runnability	6.1 $\pm$ 0.9	6.2 $\pm$ 0.9	ns	6.0 $\pm$ 1.2	6.0 $\pm$ 1.5	ns
<i>min - max</i>	4.1 - 7.4	4.9 - 7.4		4.0 - 7.4	3.9 - 8.1	
Terrain Visibility	5.4 $\pm$ 1.2	5.3 $\pm$ 1.0	ns	6.1 $\pm$ 1.3	6.2 $\pm$ 1.6	ns
<i>min - max</i>	3.1 - 7.1	3.2 - 6.2		3.7 - 7.8	3.0 - 8.3	

Variability of finishing times and running speed. A list of finishing times and running speed data is summarized in Table 2.

A variation in winner finishing times was observed for both discipline and sexes. Finishing time coefficient of variation (CV) values ranged from 5.6% (male) to 4.9% (female) for the long-distance races and from 2.5% (male) to 2.7% (female) for the middle-distance races. Moreover, for 16 of the 44 analyzed races, the finishing times were longer than that predicted in the IOF competition rules (International Orienteering Federation, 2020). In fact, for the middle-distance race, the mean male winner times were longer than in the rules (35.2 min vs. 30- to 35-min rule). The running speed was significantly different between sexes, with a reduction from the shorter (middle) to the longer distance (long). Within the analyzed years, the speed ratios between males and females were 1.29 in the middle-distance races and 1.28 in the long-distance races.

Within the top 30 ranked athletes, the distribution of finishing times and running speed was greater in female athletes. The data presented in Table 2 shows a significant difference regarding range and interquartile range (IQ) finishing times in the middle-distance races. Again, no significant differences were determined for the long distance since the winning time rule was different between sexes, but even with a lower winning time, the female group showed a higher range and IQ than the male group.

Table 2: Finishing times and running speed data (mean $\pm$ SD, min-max) from forest individual races of the World Orienteering Championships from 2009 to 2019. Times are expressed in minutes.

	Middle distance			Long distance		
	Female	Male	<i>p</i>	Female	Male	<i>p</i>
Finish time winner	34.8 $\pm$ 2.7	35.2 $\pm$ 2.4	ns	77.4 $\pm$ 4.8	97.7 $\pm$ 5.4	-
<i>min - max</i>	30.0 - 38.3	30.6 - 38.2		69.0 - 86.4	90.2 - 107.5	
Top30 mean Finish time	39.7 $\pm$ 2.8	38.4 $\pm$ 2.7	ns	89.7 $\pm$ 6.2	108.1 $\pm$ 7.1	-
<i>min - max</i>	34.9 - 43.3	33.7 - 42.3		83.2 - 102.6	99.9 - 124.6	
Top30 Finish time Range	8.7 $\pm$ 1.9	5.9 $\pm$ 1.6	<0.01	21.7 $\pm$ 5.0	18.7 $\pm$ 5.5	-
<i>min - max</i>	5.3 - 12.0	3.6 - 9.9		14.2 - 33.6	12.3 - 32.1	
Top30 Finish time Interquartile range	3.4 $\pm$ 0.7	2.4 $\pm$ 0.6	<0.01	9.1 $\pm$ 2.7	7.4 $\pm$ 2.3	-
<i>min - max</i>	1.7 - 4.3	1.2 - 3.1		6.3 - 14.9	4.1 - 10.9	
Running speed winner	6.9 $\pm$ 0.6	8.9 $\pm$ 0.7	<0.01	6.8 $\pm$ 0.9	8.7 $\pm$ 1.0	<0.01
<i>min - max</i>	5.4 - 7.8	7.3 - 9.8		5.3 - 8.0	6.8 - 10.2	
Top30 mean Running speed	7.6 $\pm$ 0.6	9.5 $\pm$ 0.7	<0.01	7.5 $\pm$ 0.9	9.3 $\pm$ 0.9	<0.01
<i>min - max</i>	6.0 - 8.3	8.1 - 10.2		6.1 - 8.8	7.6 - 10.8	
Top30 Running speed Range	1.7 $\pm$ 0.3	1.5 $\pm$ 0.3	ns	1.9 $\pm$ 0.4	1.6 $\pm$ 0.3	ns
<i>min - max</i>	1.2 - 2.5	1.0 - 2.1		1.2 - 2.5	1.2 - 2.0	
Top30 Running speed Interquartile range	0.7 $\pm$ 0.1	0.6 $\pm$ 0.2	ns	0.7 $\pm$ 0.1	0.6 $\pm$ 0.1	ns
<i>min - max</i>	0.4 - 0.9	0.3 - 0.9		0.6 - 1.0	0.4 - 0.8	

Effect of course characteristics on finishing times and running speeds. We investigated these effects by analyzing the correlation between the collected variables and the top 30 finishing times and running speeds for both disciplines, as presented in Tables 3 and 4.

Table 3: Correlation between course characteristics and top 30 finishing times and running speeds in the long-distance races of the World Orienteering Championships from 2009 to 2019

	Finish time				Running Speed			
	Female		Male		Female		Male	
	<i>r</i>	BCa 95% CI ^a	<i>r</i>	BCa 95% CI ^a	<i>r</i>	BCa 95% CI ^a	<i>r</i>	BCa 95% CI ^a
Race length (km)	-.014	-.649 to .772	.010	-.511 to .752	.858**	.666 to .977	.803**	.525 to .967
Distance climbed (m)	.166	-.411 to .594	-.260	-.870 to .358	-.392	-.715 to -.071	-.075	-.621 to .421
No. control points	-.368	-.750 to .054	-.065	-.663 to .506	.535	.222 to .829	.164	-.391 to .720
EF race length (km)	.074	-.501 to .781	-.155	-.515 to .436	.693*	.231 to .928	.735**	.314 to .988
Course Technical Difficulty	.744**	.059 to .915	.626*	-.193 to .861	-.827**	-.958 to -.603	-.856**	-.978 to -.189
Terrain Morphology	.190	-.402 to .576	.041	-.709 to .565	-.646*	-.876 to -.188	-.530	-.972 to .113
Terrain Runnability	.385	-.329 to .786	.354	-.364 to .687	-.861**	-.976 to -.635	-.882**	-.975 to -.629
Terrain Visibility	-.202	-.744 to .352	-.500	-.798 to .208	.456	.000 to .841	.512	.027 to .876

* $p < 0,05$ ** $p < 0,01$ ^aBCa 95% CIs are based on 1000 bootstrap samples. BCa, bias-corrected and accelerated bootstrap.

In the middle-distance races, female finishing time showed a large positive correlation with race length. When we normalized the race length to the distance climbed, we observed that the correlation between that variable and finishing time was very large for both sexes. We highlight the large to very large correlation between course technical difficulty and finishing time in the long-distance races.

For both analyzed disciplines and sexes, running speed showed a very large positive correlation with race length (with the exception of the male middle-distance races) and a large to very large negative correlation with course technical difficulty.

In long-distances races, running speed showed a very large negative correlation with terrain runnability, whereas for the middle-distance courses, both sexes showed large to very large negative correlation with distance climbed. The males presented unique correlations between running speed and terrain morphology (large) and runnability (very large) in middle-distance races. Females presented a unique correlation between terrain morphology (large) and running speed for the long-distance races.

Table 4: Correlation between course characteristics and top 30 finishing times and running speeds in the middle-distance races of the World Orienteering Championships from 2009 to 2019

	Finish time				Running Speed			
	Female		Male		Female		Male	
	<i>r</i>	BCa 95% CI ^a	<i>r</i>	BCa 95% CI ^a	<i>r</i>	BCa 95% CI ^a	<i>r</i>	BCa 95% CI ^a
Race length (km)	.643*	-.179 to .984	.412	-.223 to .942	.711*	-.252 to .906	.468	-.162 to .775
Distance climbed (m)	.038	-.678 to .853	.638*	.126 to .909	-.616*	-.913 to .694	-.797**	-.967 to -.144
No. control points	.217	-.318 to .755	-.060	-.728 to .609	.496	-.227 to .828	.383	-.121 to .756
EF race length (km)	.723*	.251 to .960	.702*	.240 to .973	.555	-.295 to .829	.085	-.299 to .371
Course Technical Difficulty	.326	-.582 to .790	.568	-.154 to .971	-.659*	-.986 to -.011	-.676*	-.981 to .147
Terrain Morphology	.415	-.215 to .840	.414	-.207 to .907	-.226	-.903 to .156	-.673*	-.928 to .326
Terrain Runnability	-.114	-.673 to .688	.293	-.299 to .755	-.498	-.880 to .236	-.753**	-.916 to -.507
Terrain Visibility	.560	.011 to .931	.505	-.034 to .879	-.184	-.509 to .046	.006	-.836 to .673

* $p < 0,05$ ** $p < 0,01$ ^aBCa 95% CIs are based on 1000 bootstrap samples. BCa, bias-corrected and accelerated bootstrap.

Effect of course characteristics on the variability of the top 30 finishing times. We investigated these effects by analyzing the correlation between the collected variables and IQ range for both disciplines. In male long-distance races, we found a very large positive correlation between IQ range and terrain runnability ($r = 0.77$, BCa 95% CI [0.50, 0.93], $p = 0.005$) and large to very large negative correlation between IQ range and terrain visibility, ($r = -0.72$, BCa 95% CI [-0.86, -0.54], $p = 0.005$), number of CP, ($r = -0.60$, BCa 95% CI [-0.90, -0.28], $p = 0.048$) and EF race length ($r = -0.77$, BCa 95% CI [-0.88, -0.71], $p = 0.006$).

Discussion

Our investigation provided novel insights into the effects of course characteristics on finishing times and running speeds of WOC winners, as well as characterized the ratio between male and female courses.

Because the courses were set according to the defined rules of the IOF (International Orienteering Federation, 2020), unsurprisingly, we found statistical differences in course lengths between male to female athletes. When calculating mean running speed and thus normalizing the different winning times for the long-

distance discipline, we found a sex difference of $22\% \pm 4\%$ (range= 13–27%) for the middle-distance discipline and $22\% \pm 3\%$ (range= 17–27%) for the long-distance discipline. These differences are higher than those found for middle- and long-distance running (11%), cross-country skiing (10–12%) and middle- and long-distance kayaking (15–17%) (Sandbakk, Solli, & Holmberg, 2018). This greater sex differences found for the individual forest orienteering disciplines may be due to the terrain type encountered during competition because heavy forest terrain requires more VO_2 (Jensen et al., 1994, 1999), thus highlighting the physiological differences between sexes (Cheuvront, Carter, Deruisseau, & Moffatt, 2005). Furthermore, because running speed is also influenced by navigational tasks, the better performance of males in spatial orientation tasks (Coluccia & Louse, 2004) might contribute to a higher difference in running speed between the sexes.

These findings are in accordance with the studies of Gjerset et al. (1997), Moser et al. (1995) and Bird et al. (2001), where the authors reported higher sex differences in orienteering than in other endurance sports with differences ranging from 19% (Bird et al., 2001) to 32% (Gjerset et al., 1997). Interestingly, Gjerset et al. (1997) also calculated the sex differences in similar cross-country races. The investigation showed that the sex difference reduced from 32% in an orienteering race to 21% in cross-country race, confirming the influence of the navigational tasks on running speed. In all these studies, the authors compared the means of the entire group. Applying this principle to our study, the differences between sexes were 20% in the middle-distance races and 19% in long-distance races.

When exploring the variability of the finishing times within the top 30 best-ranked male and female athletes in WOC races, a clear difference between sexes was found. Upon analyzing the interquartile range of the top 30 ranked athletes in WOC races, female athletes exhibited greater variability in finishing times both in the long-distance ($\text{CV } 11.7\% \pm 3.4\%$ for females; $7.5\% \pm 2.1\%$ for males) and in middle-distance discipline ($\text{CV } 9.9\% \pm 2.1\%$ for females; $6.8\% \pm 1.9\%$ for males). This confirmed the findings of Hébert-Losier et al. (2015), where the authors found that female athletes exhibit a higher between-athlete difference in performance than their male counterparts.

The analysis of the winners' finishing time in both disciplines showed a coefficient of variation ranging from 2.5% to 5.6%. If we take into account that Hébert-Losier et al. (2015) refers the smallest worthwhile effect for WOC performance enhancement to be between 0.96% and 3.5%, most of this effect can be offset by the course characteristics.

On this note, in the middle-distance discipline, even with a smaller CV of the winner's times than in the long-distance discipline, we observed a strong positive correlation between course length and finishing times. For female athletes, the longer the length of the course, the higher the finishing time. There is a need to normalize the course length in relation to climbing, as proposed by Lauenstein et al. (2013), as we found not only a higher correlation value by relating finishing times with EF race length instead of with simple race length and a statistical significance for both sexes.

From our analysis, course characteristics have a large to very large effect on running speed for both disciplines and sexes. The large to very large positive correlation between race length and running speed translates to athletes being slower on shorter courses. This reveals the true nature of forest orienteering, as terrain type influences the physiological performance of athletes (Jensen et al., 1994, 1999) with a clear increase in running economy between path running, light and heavy terrain, as well as a reduction in running speed from lighter to heavier terrain (K Hébert-Losier, Jensen, Mourot, & Holmberg, 2014). For this reason, course setters tend to compensate by lengthening courses on easier terrain to keep the winning times within the IOF competition rules. The very large negative correlation between terrain runnability and running speed reinforces these findings.

The physiological influence of running on heavy terrain may also explain the correlation between terrain runnability and finishing times in terms of IQ range, as our data suggests that, in male long-distance races, terrain with harder runnability lead to greater time differences between the athletes. We also observed that terrain visibility and number of control points have a significant correlation with finishing times in terms of IQ range. In our opinion, low visibility terrain and a low number of control points will increase the difficulty of navigational tasks, which can then lead to higher differences between athletes.

To our knowledge, our study is the first to relate the technical difficulty of a course with running speed. The large to very large strong negative correlation with running speed, for both sexes and disciplines, shows that an increase in the technical difficulty of the course leads to slower running speeds. This objective relation is in line with the theory of Eccles et al. (2002b). In their work, the authors mentioned that a reduction in running speed may be observed due to the need to increase the attentional focus on map reading and environmental complexity. Because complex navigation environments have less distinguishable features, map simplification becomes more difficult, hindering the ability of an athlete to anticipate the navigation, consequently reducing their running speed. In fact, increasing the map reading time seems to reduce the chance of making a navigational error, which could positively affect performance time more than reducing running speed (Eccles et al., 2002b). On this matter, taking into account that, as stated in the IOF competition rules (International Orienteering Federation, 2020), middle-distance races should focus on the combination between high-speed running and navigation on technically complex terrain, the large to very large correlation between distance climbed and running speed is a worthy remark to course setters. This means that increasing the climbing will

reduce running speed, thus not complying with the competition rules.

This is a study with a longer set of data regarding WOC races (eleven years studied). With this data set, we believe that the results provide meaningful information to the foot orienteering community, especially regarding increasing the awareness of monitoring a course's technical difficulty and terrain type. Furthermore, we believe that our approach can lead to a future research project regarding the influence of course characteristics on orienteering performance.

Conclusions

Our study provides insights into the effect of course characteristics on an athlete's performance in the World Orienteering Championships. Orienteering coaches and athletes should focus on obtain precise characterization of the type of the terrain for races because it has a clear effect on running speed. Course setters should pay extra attention to balancing course length and technical difficulty with the terrain type to meet the IOF competition rules, as we observed that in 36% of the WOC races, the winning time was outside the rules.

From a practical point of view, if course setters want to increase the difficulty of navigational tasks, they should seek competition terrains with low visibility terrain and reduced runnability and prepare courses with a low number of control points. This will also increase the differences between athletes. We recommend future studies to develop an objective tool to characterize the terrain type and course technical difficulty.

We also conclude that sex differences in orienteering performance are higher than in other endurance sports perhaps due to the terrain type encountered during competition and by the navigational tasks, with women showing higher variability in finishing times than their male counterparts.

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