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Pacing in ultra-marathon running: the Western States 100-mile endurance run 2006–2023

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Pacing has been investigated in different running races, including ultra-marathons. We have, however, little knowledge about pacing in ultra-trail running. To date, no study has investigated pacing in one of the most iconic ultra-trail running races, the 'Western States 100-Mile Endurance Run' (WSER), which covers 160 km (100 miles) and includes significant elevation changes (6000 vertical meters uphill and 7500 vertical meters downhill). Therefore, the aim of the study was to investigate pacing for successful finishers in WSER regarding gender, age, and performance level. Official results and split times for the WSER were obtained from the race website, including elevation data from 3837 runners, with 3068 men (80%) and 769 women (20%) competing between 2006 and 2023. The mean race speed was calculated for each participant, as well as the average mean checkpoint speed for each of the 18 race checkpoints (17 aid stations and finish point). The percentage of change in checkpoint speed (CCS) in relation to the average race speed was calculated. CCS was calculated for each of the 18 checkpoints to evaluate each runner's pacing strategy. The average change in checkpoint speed (ACCS) of each participant was calculated as a mean of the 18 CCSs. Eight age groups were formed. Since there were very few runners younger than 25 and older than 65 years, these age groups were merged into < 30 and 60 > groups, respectively. Four performance groups were formed by four quartiles, each consisting of 25% of the total sample separately for men and women. Pacing shows great variability between checkpoints in both men and women, mainly influenced by elevation. Although the race profile is mostly downhill, it appears that the pacing trend is towards positive pacing. The differences between men and women were mainly at the beginning of the race (men start faster) and towards the end (men slow down more). Men have more pacing variability than women, with significant differences in the youngest age group, as well as the 40–44 and 50–54 age groups. In addition, younger men have more variability in pace compared to older men. There are no significant differences in age groups in women. Finally, the slowest and fastest ultra runners had less pacing variability than medium level runners. Pacing in WSER-runners shows great variability between checkpoints in both men and women. Pacing is positive and highly influenced by elevation. Men start faster than women, and men slow down more than women. Pacing differs in male but not in female age group runners. The slowest and fastest ultra runners had less pacing variability than medium level runners.

Keywords Ultra-endurance, Performance, Running, Trail, Variability

Pacing in sports describes the strategy by which an athlete distributes work and energy throughout a specific exercise task[1]. When this concept applies to running, it refers to changes in speed during a race or training[2]. To date, different pacing strategies have been identified based on the quotient of the time to cover a given distance to this distance, such as negative (i.e., the time needed to cover a given distance decreases; that is, the speed increases), all-out, positive, even, parabolic-shaped and variable pacing strategies[1].

In running, pacing has been mainly investigated in shorter running distances such as 1500 m track running[3,4] and longer track distances such as 10,000 m[5]. In longer running distances, pacing during a marathon has been

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investigated for different groups, such as elite runners[6], recreational runners[7], and female compared to male runners[8]. The main focus of the abovementioned studies was to examine which pacing optimized performance, i.e., how the fast runners distributed their effort during a race, and how pacing differed by gender, age and performance level.

In ultra-marathons, i.e., races longer than 42 km or lasting more than 6 h, there is little research to investigate time-limited runs such as a 6-h run[9] or a 24-h run[2] and distance-limited runs such as a 65-km mountain ultra-marathon[10], 100-km ultra-marathons[11–13] or 100-mile ultra-marathons[14,15]. Interestingly, the pacing in a 6-h race has been shown not only to relate to performance but also to perceived exertion and fatigue[9]. Furthermore, the pacing in a 24-h race was shown to vary by gender and performance level, with men and faster runners presenting less variation in speed during the race[2]. With regards to 100-miles ultra-marathon race, it has been observed that the fastest runners presented the least variation in their speed during the race[9].

In longer ultra-marathons with large elevations, very little data about speed changes during a race exists. A recent study has investigated the pacing in the UTMB (Ultra-Trail du Mont Blanc) covering a distance of 172 km and more than 10,000 m of altitude[16]. While the UTMB is one of the best-known ultra-marathons in the world, pacing in another 'iconic ultra-marathon', the 'Western States 100-Mile Endurance Run' (WSER), has not been investigated.

To date, scientific interest in WSER was limited mainly to the investigation of participation and performance[17], influential factors for a successful race outcome[18], kidney injury[19], gastrointestinal distress[20], exercise-associated hyponatremia[21], sodium supplementation[22] and rehydration[23], nutritional aspects[24], the influence on the heart[25] and on specific hormones[26] and medical care during the race[27].

A study investigating the pacing by these ultra-marathoners regarding gender, age and performance level is missing. To date, two studies have investigated pacing in WSER[15]. In one study, the pacing of elite runners was investigated[14], while in the other study, the influence of environmental conditions and performance level[15] was examined. The aim of the study was to investigate the pacing of successful finishers in WSER in terms of gender, age, and performance level. Regarding the findings for pacing in UTMB[16], where even pacing throughout the UTMB correlated with faster finishing times, we hypothesized also for WSER that the fastest runners would evenly pace during the race.

Methods

Ethical approval

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

Subjects

For this study, we have included official results and split times for WSER[28]. In total, the results of 3837 runners from 2006 to 2023 were included in the analysis (selection criteria are presented in Fig. 1). In particular, results of 3,068 men (80%) and 769 women (20%) were analysed.

The race

The WSER is the oldest 100-mile trail race in the world. Starting in Olympic Valley, California, USA, near the site of the 1960 Winter Olympics and ending 100.2 miles later in Auburn, California, Western States has come to represent one of the ultimate endurance tests in the world in the decades since its inception in 1974[28]. Every year, around 370 runners compete in WSER. Around 270 runners are selected via lottery, while around 100 runners are automatically selected (top-ten finishers from the previous year, sponsors, race admins, winners of specific races, etc.). To enter the lottery process, interested athletes must have completed a qualifying race (distances 100–400 km) from the official list[29] within a one-year period (for example, for the 2024 edition, from November 2022 to November 2023).

The terrain is difficult, often with snow on the highest passes and high temperatures in the deep valleys toward the end of the run[30]. Temperatures vary between 59 degrees F (15 °C) and 89 degrees F (31.7 °C)[31]. There are 6000 vertical meters uphill and 7500 vertical meters downhill to conquer (for more detailed information on elevation, see Table 2). Since its start in 1974, the course had to be changed several times. Nowadays, the race follows the same basic course used since 1986 with three slightly different configurations: from 1986 to 2001, from 2002 to 2005, and the present one since 2006[32]. In the current version, a total of 20 aid stations (checkpoints) must be passed[33]. In this study, three checkpoints (Dardanelles, Ford's Bar, and Robie Point) were excluded from the analysis due to the large amount of missing data. In particular, out of the 14 analyzed races, the checkpoints at Dardanelles, Ford's Bar, and Robbie Point appeared only 5, 3, and 10 times, respectively. This could jeopardize the accuracy of further analyses. The lengths of these checkpoints are merged with the next available checkpoint (Table 1).

Data analysis

Race results and split times were obtained from the official race website[34]. Elevation data was also extracted from the official race website[35] using a custom-made Python script. For further analysis, several dependent and independent variables were considered.

Dependent variables

Mean race speed was calculated for each participant, as well as the average mean checkpoint speed for each of the 18 race checkpoints (17 aid stations and the finishing point). The mean race and checkpoint speeds for each

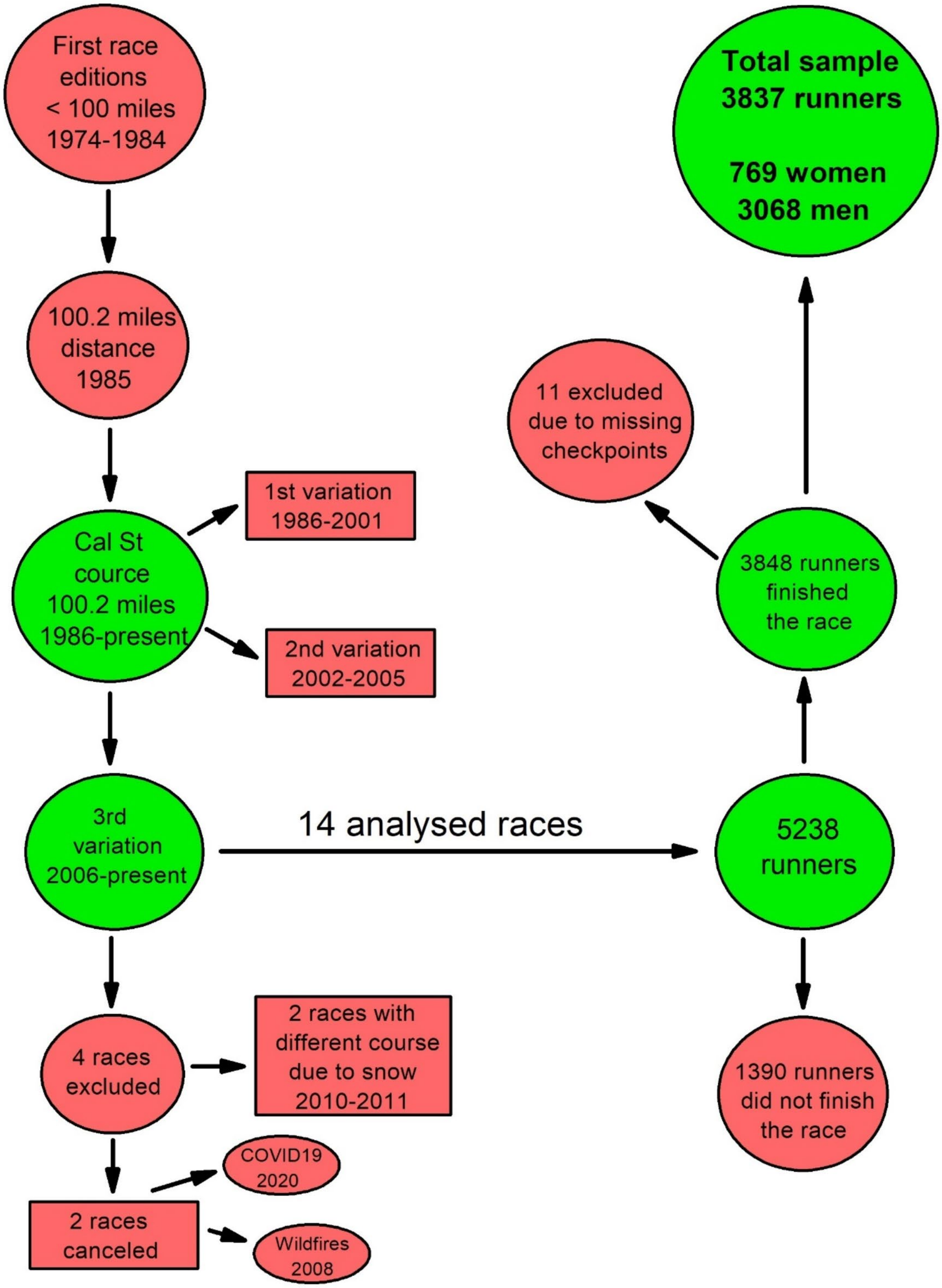

Fig. 1. Flow chart for selection criteria; red shapes indicating exclusion, green shapes indicating inclusion.

runner were determined by dividing the distance covered by the time taken to complete it. Additionally, the percentage change in checkpoint speed (CCS) relative to the average race speed was calculated. For example, if a runner finishes one checkpoint at 7 km/h on average and the entire race on average at 8 km/h, his CCS for this checkpoint will be −12.5% slower than the average race speed. This was done for all 18 checkpoints to assess each runner's pacing strategy[36]. These metrics provide an overall view of the runner's performance during the race as well as at specific intervals. Finally, each participant's average change in checkpoint speed (ACCS) was calculated as a mean of the 18 CCSs. Note that using both positive and negative percentage values could lower

						Women				Men			
CP number	CP name	Cumulative CP length (km)	CP length (km)	Ascent (m per km)	Descent (m per km)	Mean speed (kmh)	St. Dev.	Min.	Max.	Mean speed (kmh)	St. Dev.	Min.	Max.
1	Lyon ridge	16.6	16.6	56.4	44.1	6.90	1.07	4.78	10.05	7.18	1.11	4.59	10.69
2	Red ridge star	25.4	8.9	46.7	33.2	6.98	1.10	3.96	10.21	7.28	1.14	3.40	11.54
3	Duncan canyon	39.3	13.8	21.9	56.5	8.60	1.40	4.55	12.58	8.90	1.48	5.65	14.42
4	Robinson flat	48.8	9.5	59.3	28.4	6.09	1.04	3.37	9.66	6.22	1.11	3.58	10.96
5	Miller's defeat	55.4	6.6	15.9	45.0	7.04	1.78	3.92	13.02	6.96	1.68	3.07	14.66
6	Dusty corners	61.2	5.8	4.9	52.6	9.72	1.79	6.00	14.66	9.74	1.90	5.14	17.21
7	Last chance	69.7	8.5	3.7	27.4	8.64	1.61	5.44	13.36	8.74	1.69	4.74	14.62
8	Devils thumb	76.9	7.2	85.9	92.6	5.14	0.96	3.02	9.66	5.17	1.03	2.12	9.88
9	El Dorado Creek	85.1	8.2	19.9	98.4	7.19	1.64	3.16	13.68	7.16	1.65	3.37	14.48
10	Michigan bluff	89.6	4.5	94.1	10.2	4.56	0.76	2.65	7.72	4.53	0.80	2.53	8.72
11	Foresthill	99.8	10.1	35.6	43.3	6.40	1.30	3.38	10.89	6.40	1.34	2.87	12.17
12	Dardanelles/peachstone	113.8	14.0	38.8	77.5	6.51	1.51	3.94	12.23	6.59	1.55	3.33	13.29
13	Ford's bar/rucky chucky	125.5	11.7	33.5	48.9	6.19	1.48	2.97	11.38	6.25	1.53	2.70	12.37
14	Green gate	128.4	2.9	69.1	26.9	4.19	1.05	1.45	8.26	4.16	1.06	1.30	10.22
15	Auburn lakes trails	137.1	8.7	39.5	36.5	5.90	1.23	2.04	10.86	5.99	1.33	2.34	12.13
16	Quarry road	146.0	8.9	11.1	33.7	6.67	1.34	2.38	11.80	6.73	1.57	2.01	14.35
17	Pointed rocks	151.8	5.8	52.1	10.4	5.33	0.87	2.29	9.02	5.38	1.00	2.07	10.22
18	Robie point/finish	161.0	9.2	30.0	35.9	5.65	1.17	3.13	11.08	5.62	1.22	2.37	11.86

Table 1. Race specifications and the descriptive values of men's and women's race and checkpoint speed. **CP* checkpoint, *St.Dev.* Standard deviation, *Min* minimum, *Max* maximum.

the means of CCS and ACCS. Therefore, to address this issue, we have transformed all percentage variables to their absolute values (i.e. only positive values were used for statistical analysis, while both positive and negative values were depicted on the graphs). These variables were chosen since they were proven to be reliable, valid, and sensitive enough to be routinely used when exploring pacing in long and ultra-distance running[37]. Since all pacing variables were expressed as percentages, data were log-transformed for the analyses and then back-transformed according to existing methods[38].

Independent variables
Eight age groups were formed: <30; 30–34; 35–39; 40–44; 45–49; 50–54; 55–59; 60 > years of age (Table 2). Since there are very few runners younger than 25 and older than 65, they were merged into < 30 and 60 > groups, respectively. Furthermore, four performance groups were formed by four quartiles, each consisting of 25% of the total sample separately for men and women. They were later merged to form a high-level running group (HL), moderate-to-high-level running group (MHL), moderate-to-low-level running group (MLL), and low-level running group (LL)[36].

Statistical analysis

Descriptive statistics were calculated as mean and standard deviation before all statistical tests. Data distribution normality was confirmed by the Kolmogorov–Smirnov test and visual inspection of histograms and QQ plots. A mixed between-within analysis of variance (ANOVA) was performed on absolute values of CCS to test differences between checkpoints (i.e., checkpoints 1–18; within-subjects factor), gender (i.e., men and women; between-subjects factor) as well as their interaction (checkpoint × gender). In addition, one two-way ANOVA was performed on ACCS to assess differences between 8 age groups (i.e., < 30; 30–34; 35–39; 40–44; 45–49; 50–54; 55–59; 60 > years of age), gender (i.e., men and women) as well as their interaction (age group × gender). Finally, another two-way ANOVA was also performed on ACCS to assess differences between 4 performance groups (i.e., HL, MHL, MLL, LL), sex (i.e., men and women), as well as their interaction (performance group x gender). For all ANOVAs, the post hoc Bonferroni test was performed. Effects size was presented via eta squared (η^2), where the values of 0.01, 0.06, and above 0.14 were considered small, medium, and large, respectively. The alpha level was set at $p < 0.05$. All statistical tests were performed using Microsoft Office Excel 2021 (Microsoft Corporation, Redmond, WA, USA) and SPSS 26 (IBM, Armonk, NY, USA).

Results

Table 1 presents race specifications, particularly race checkpoints, their numbers, distance, and elevation gain per kilometer. The same table shows the mean race and the speed of the checkpoint for women and men, together with other descriptive data. Regardless of gender, the WSER runners showed rather variable running speeds throughout the race, which was mainly influenced by elevation (Table 1). However, it appears that even though the overall elevation is decreasing throughout the race, the mean speed is trending down.

To further assess the pacing of WSER-runners, mixed between-within ANOVA was performed on absolute values of CCS to assess differences between women and men regarding the race checkpoint. As a result, a significant main effects of checkpoint [$F_{(17,2579)} = 3146.2$, $\eta^2 = 0.55$, $p < 0.001$], sex [$F_{(17,2579)} = 9.87$, $\eta^2 = 0.004$, $p = 0.002$] and checkpoint x gender interaction [$F_{(17,2579)} = 6.99$, $\eta^2 = 0.003$, $p < 0.001$] were observed (Fig. 2). The pairwise analysis is presented in Table 3.

When the pacing was evaluated using ACSS (Fig. 3), the two-way ANOVA showed significant main effects of gender [$F_{(15,3821)} = 14.93$, $\eta^2 = 0.004$, $p < 0.001$], age [$F_{(15, 3821)} = 4.46$, $\eta^2 = 0.008$, $p < 0.001$], while no age x gender interaction was observed [$F_{(15, 3821)} = 0.642$, $\eta^2 < 0.001$, $p = 0.722$]. The post-hoc analysis is depicted in Fig. 3. Finally, another two-way ANOVA was applied to ACSS to asses pacing in relation to the performance (Fig. 4). The significant main effects of gender [$F_{(7,3829)} = 18.16$, $\eta^2 = 0.005$, $p < 0.001$], performance [$F_{(7,3829)} = 17.24$, $\eta^2 = 0.013$, $p < 0.001$] and performance x gender interaction was observed [$F_{(7,3829)} = 2.85$, $\eta^2 = 0.002$, $p = 0.036$]. The post-hoc analysis is depicted in Fig. 4.

Age group	Total	Women		Men	
		n	%	n	%
< 30	234	61	26.1%	173	73.9%
30–34	510	139	27.3%	371	72.7%
35–39	700	149	21.3%	551	78.7%
40–44	889	183	20.6%	706	79.4%
45–49	694	128	18.4%	566	81.6%
50–54	458	66	14.4%	392	85.6%
55–59	228	29	12.7%	199	87.3%
60>	124	14	11.3%	110	88.7%
Total	3837	769	20.0%	3068	80.0%

Table 2. Age distribution by gender

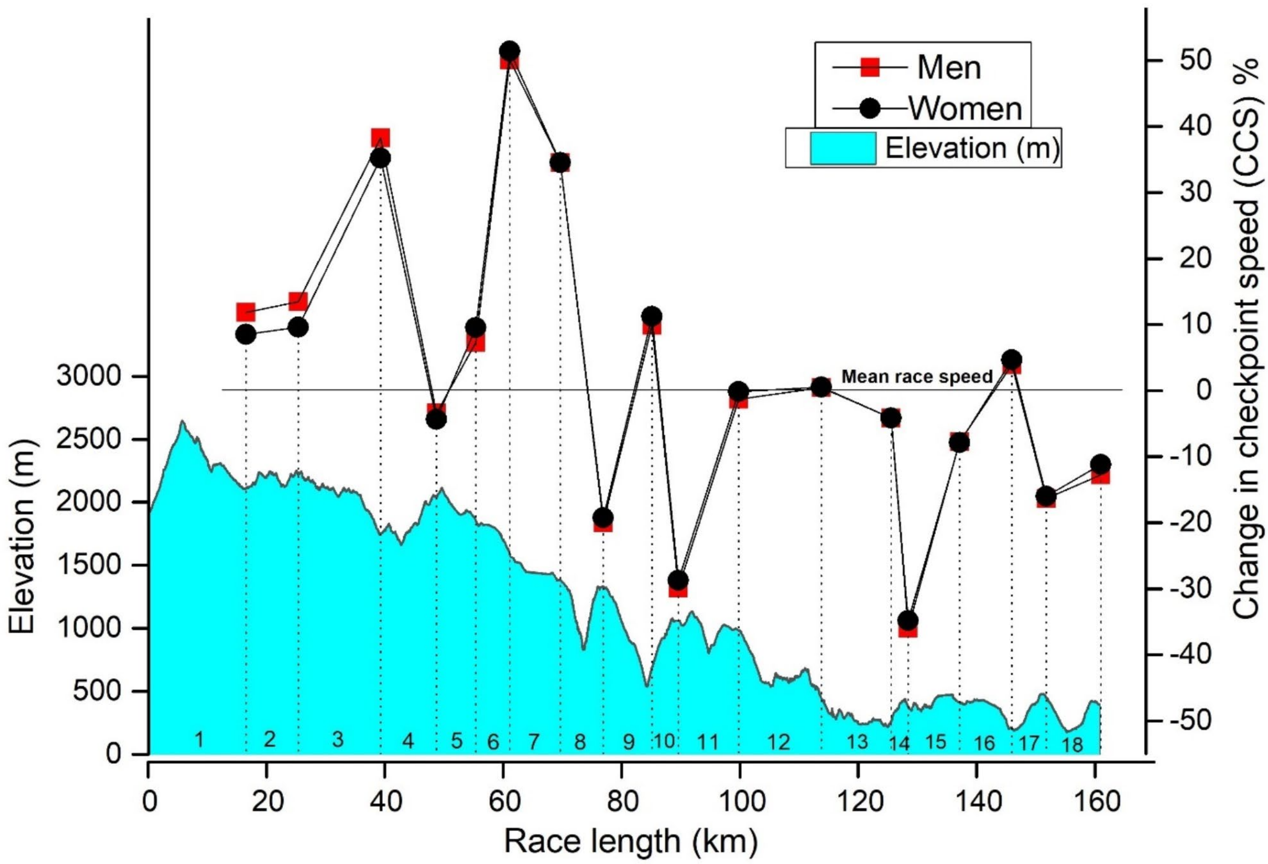

Fig. 2. Race elevation and the percentage of change in checkpoint speed (CCS) in relation to the mean race speed in men and women. *Dotted vertical lines depict race checkpoints.

Discussion

We investigated the pacing of finishers in WSER by gender, age and performance level and hypothesized that the fastest runners would pace evenly during the race. We found, however, that the pacing trend was towards positive pacing and were unable to confirm our hypothesis of an even pacing. Although the race profile is mostly downhill (Fig. 2), these runners progressively slowed down (Table 1). Potential explanations could be the length of the race since positive pacing is a general finding in ultra-endurance performance[39,40] where neuromuscular fatigue and skeletal muscle damage during an ultra-marathon of this distance and duration[41] might force athletes to slow down. However, it is also possible to increase running speed in an ultra-marathon of this distance and duration, where runners in the 'Spartathlon' were able to increase their running speed towards the end of the race (reverse J-shaped pacing)[36]. Also in 24-h ultra-marathon running, runners showed a reverse J-shaped pacing[2,42]. In ultra-marathon trail-running, uphill running seems to have the strongest relationship with overall race performance[43]. However, ultra-marathon trail-runners who were able of running downhill sections at a relatively higher speed were faster in the end[44]. Overall, a conservative pacing during uphill and downhill sections seems to be the best option in uneven terrain[45]. Potential explanations for the differences in pacing could be—in addition to elevation—environmental conditions and the performance level of the athletes. The high temperatures in the deep valleys toward the end of the run could slow the runners[46].

A further important finding was that pacing showed great variability between checkpoints in both men and women, primarily influenced by elevation. Although the significant main effect showed differences between men and woman, the effect size was small. Further analyses (Table 3) revealed that the differences between men and women were mainly at the beginning of the race (i.e. men start faster) and towards the end (i.e. men slow down more). Differences between men and women were mainly at the beginning of the race (i.e. men start faster) and towards the end (i.e. men slow down more). Differences in pacing between female and male ultra-marathoners have already been described[47]. In the 'Spartathlon' as a race of similar distance and duration, successful male finishers showed a more significant change in checkpoint speed in the first two checkpoints, whereas successful female finishers showed a more substantial change in the last checkpoint[36]. In the 'VI Rio 24-h Marines Ultramarathon', male and high-performance runners spent more time running (speed greater than 8 km/h) and less time walking (speed less than 3.5 km/h) than female and low-performance runners[2]. However, in marathon running, differences in pacing are more prominent between women and men. A study compared marathoners and 10-km runners in the 'Oslo Marathon' and found that women were less likely to slow in the marathon than men (9.85% compared to 12.70%) however, not in the 10-km race[48]. In a study comparing

CP number	CP name	Cumul. CP length (km)	CP length (km)	Ascent (m per km)	Descent (m per km)	Women		Men		Women vs. men	Women split by split	Men split by split
						Mean change in CP speed %	St. Dev	Mean change in CP speed %	St. Dev	Pairwise comparison	Pairwise comparison	Pairwise comparison
1	Lyon ridge	16.6	16.6	56.4	44.1	8.50	11.59	11.83	12.03	*< 0.001*	1.000	*0.002*
2	Red ridge star	25.4	8.9	46.7	33.2	9.62	10.20	13.44	11.73	*< 0.001*	*< 0.001*	*< 0.001*
3	Duncan canyon	39.3	13.8	21.9	56.5	35.23	10.44	38.29	12.18	*< 0.001*	*< 0.001*	*< 0.001*
4	Robinson flat	48.8	9.5	59.3	28.4	− 4.36	7.11	− 3.42	9.42	0.485	*< 0.001*	*< 0.001*
5	Miller's defeat	55.4	6.6	15.9	45.0	9.51	17.79	7.28	17.80	0.052	*< 0.001*	*< 0.001*
6	Dusty corners	61.2	5.8	4.9	52.6	51.39	15.04	50.06	16.84	0.108	*< 0.001*	*< 0.001*
7	Last chance	69.7	8.5	3.7	27.4	34.57	11.36	34.55	12.27	0.863	*< 0.001*	*< 0.001*
8	Devils thumb	76.9	7.2	85.9	92.6	− 19.26	9.80	− 20.01	7.94	0.936	*< 0.001*	*< 0.001*
9	El Dorado Creek	85.1	8.2	19.9	98.4	11.20	11.87	9.87	11.77	0.156	*< 0.001*	*< 0.001*
10	Michigan bluff	89.6	4.5	94.1	10.2	− 28.76	6.58	− 29.90	6.96	*0.001*	*< 0.001*	*< 0.001*
11	Foresthill	99.8	10.1	35.6	43.3	− 0.11	10.71	− 1.32	10.36	0.060	1.000	1.000
12	Dardanelles/peachstone	113.8	14.0	38.8	77.5	0.54	10.38	0.46	11.67	0.075	1.000	*< 0.001*
13	Ford's bar/rucky chucky	125.5	11.7	33.5	48.9	− 4.14	9.40	− 4.12	10.86	0.122	*< 0.001*	*< 0.001*
14	Green gate	128.4	2.9	69.1	26.9	− 34.80	13.86	− 35.99	11.98	*0.003*	*< 0.001*	*< 0.001*
15	Auburn lakes trails	137.1	8.7	39.5	36.5	− 7.88	11.08	− 7.74	10.53	0.640	*< 0.001*	*< 0.001*
16	Quarry road	146.0	8.9	11.1	33.7	4.69	15.27	3.94	16.43	0.243	1.000	*< 0.001*
17	Pointed rocks	151.8	5.8	52.1	10.4	− 15.99	10.47	− 16.36	10.99	0.739	*< 0.001*	*< 0.001*
18	Robie point/finish	161.0	9.2	30.0	35.9	− 11.22	13.23	− 12.75	14.28	*0.017*	*< 0.001*	*< 0.001*

Table 3. The descriptive values of men's and women's race and checkpoint percentage of change in checkpoint speed (CCS), along with pairwise comparison of gender and checkpoint differences. *Italic values depict significant differences between women and men, as well as significant differences of one checkpoint in relation to the previous one.

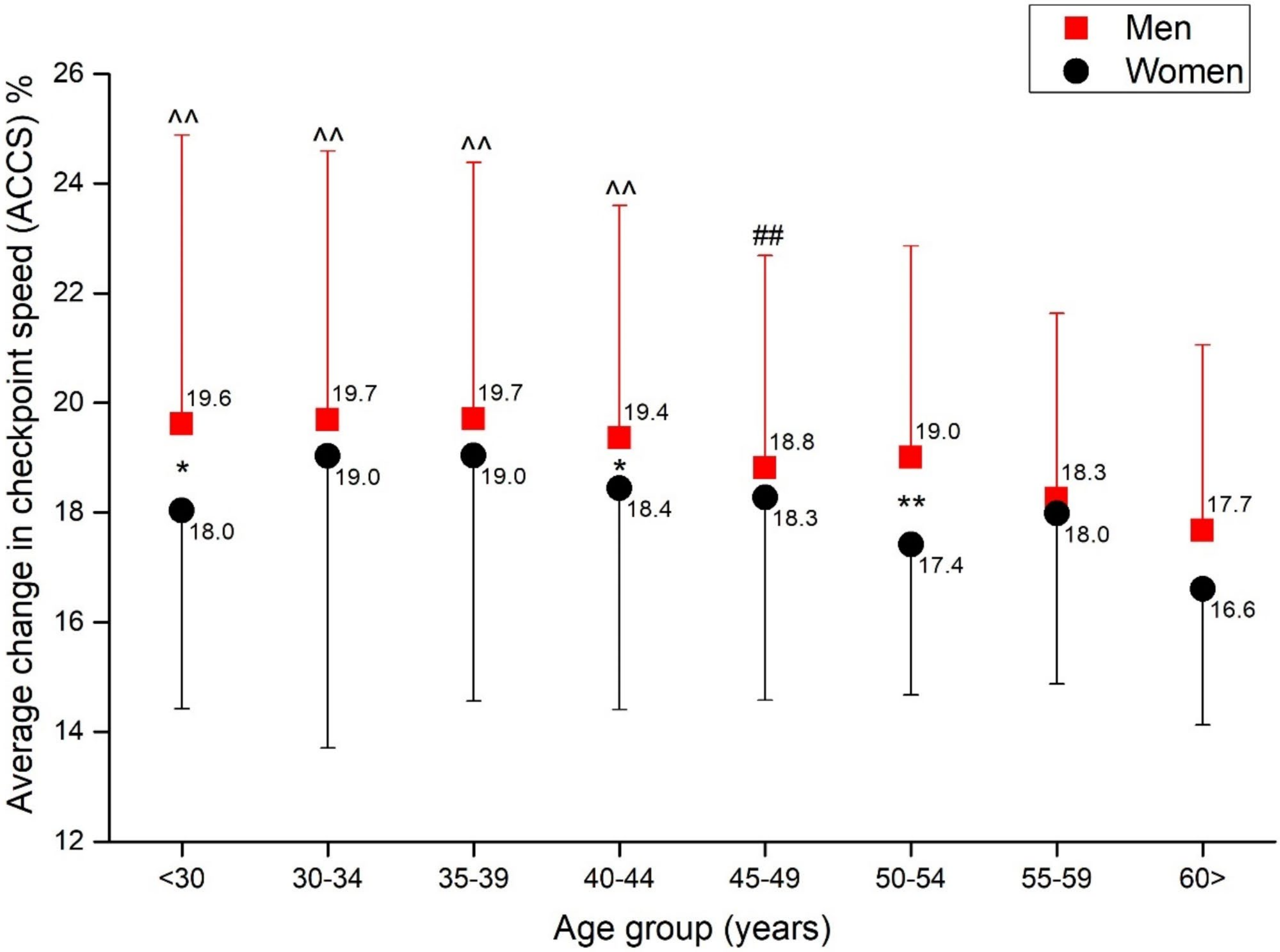

Fig. 3. The average change in checkpoint speed (ACCS) for eight age groups for men and women. **Significant difference between men and women at $p < 0.01$; *significant difference between men and women at $p < 0.05$; ^^significantly different than age groups 55–59 and 60 > at $p < 0.01$; ##significantly different than age group 35–39 at $p < 0.01$.

marathon and half-marathon in the 'Vienna City Marathon', marathon runners showed greater variability in pacing than half-marathon runners[49]. A potential explanation could be that shorter distances (i.e., 10 km and half-marathon) are not as demanding as marathon running, and in ultra-marathon running, there seems to exist a selection of good and experienced runners[50]. This may be the reason why marathon running shows the largest gender gap in pacing variability. Differences in pacing based on gender have also been reported for IRONMAN triathlon[40], marathon[51] and 10 km[52] running. In runners competing between 2015 and 2018 in the 'Oslo Marathon', women were less likely to slow than men[48]. In the Bolder Boulder 10 km road race for the years 2008–2013, fast men slowed more than fast women[52]. A potential explanation that slowed more down than women could be environmental aspects. A study investigating marathon runners showed that higher temperatures slowed more down in a marathon than lower temperatures[53].

Regarding age, men have more pacing variability than women, with significant differences in the youngest age group, as well as the 40–44 and the 50–54 age groups (Fig. 2). Also, younger men have more variability in pace compared to older men. However, there are no significant differences in age groups among women (Fig. 3). Differences in pacing by age have already been documented in ultra-marathon[47] and marathon[49] running. Considering the 'Spartathlon' as an ultra-marathon of longer distance/duration, age and gender did not affect the average checkpoint speed[42]. However, a study investigating the interaction between age and gender in the 'Comrades Marathon' showed that the performance gap between women and men was less in the older (Master 50–59 years, and Grandmaster > 60 years) as compared to the younger age groups (Senior 20–39 years, and Veteran 40–49 years). This difference in race times between men and women became less over time in a longitudinal and was quite small (12 min) in the Grandmaster category[54]. In marathon runners competing in the 'Oslo Marathon', pace changing is more prominent in both the youngest and the oldest marathoners compared to other age groups[48]. In the 'Vienna City Marathon', women showed no differences in pace variability with respect to age group, while younger (< 30 years) and older (> 60 years) men showed a greater variability in pace than runners in other age groups[49]. Furthermore, younger female and male half-marathoners showed the fastest end spurt compared to older age groups and marathoners[49]. A potential explanation for why younger men vary

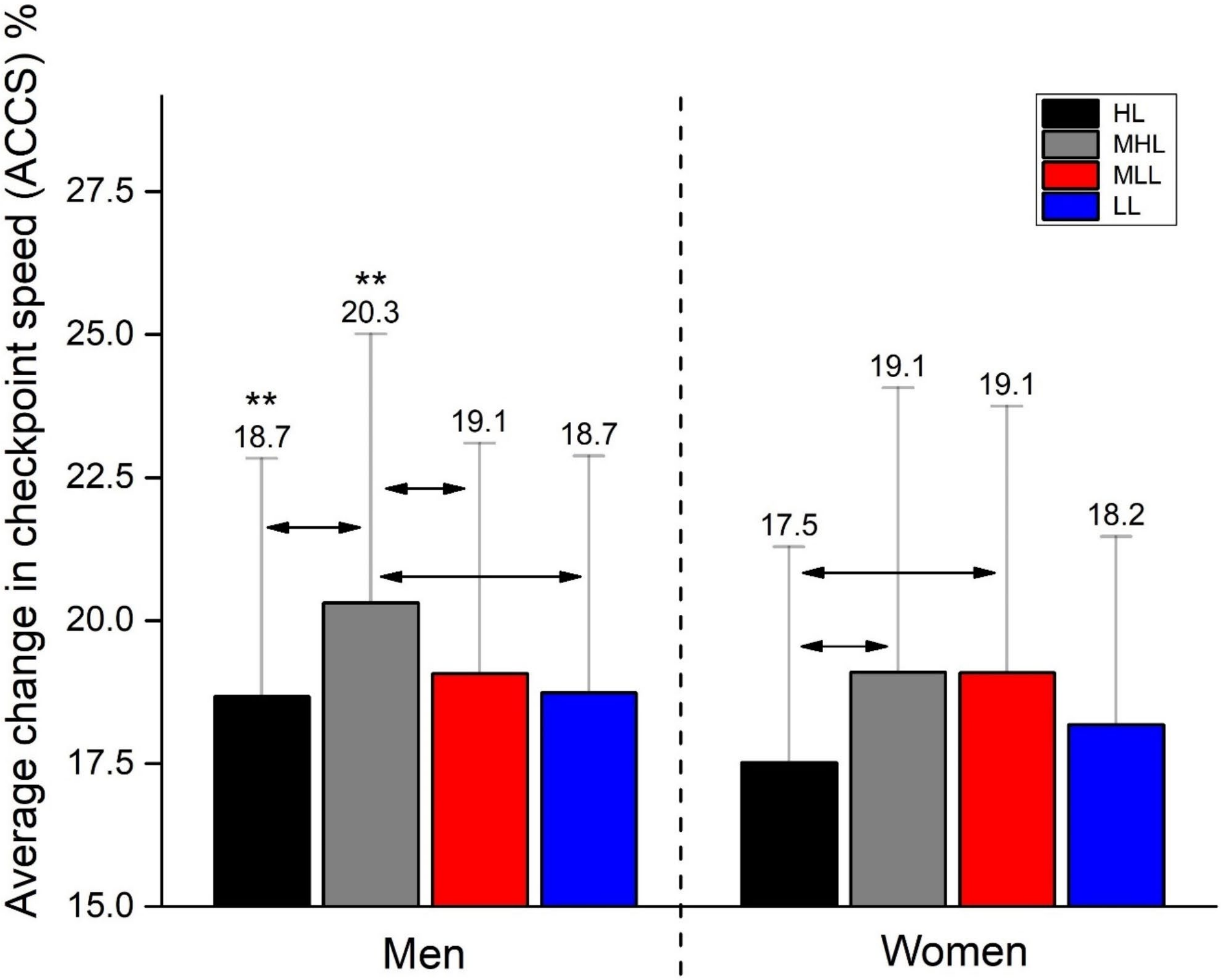

Fig. 4. The average change in checkpoint speed (ACCS) for four performance groups for men and women. Arrows represent a significant difference between performance groups within sex at $p < 0.01$; **significantly different than women at $p < 0.01$.

more in pacing in marathon running could be experience[55]. A study investigating marathon runners competing in the 'New York City Marathon' with similar race times and at different ages showed that older runners pace differently (smaller changes) than younger runners with a similar race time[56]. Similarly, a study investigating 186 men and 133 women marathoners from the 2005, 2006, and 2007 races of a midwestern U.S. marathon showed that older marathoners, women, and faster marathoners are better (i.e. more even) pacers than younger marathoners, men, and slower marathoners, respectively[55].

Regarding performance level, the slowest and faster performance groups showed less pacing variability than the medium-level groups (Fig. 4). This finding confirms recent findings for ultra-marathoners competing in the 'Spartathlon'. In that race, the slowest and the fastest ultra-runners showed fewer changes in average checkpoint speed than the two medium groups in both men and women[36]. Nevertheless, in marathoners, pacing is different regarding performance groups[56]. In marathoners competing in the 'New York City Marathon', finishers in older age groups showed a relatively more even pace compared to finishers in younger age groups. This trend was more notable in the relatively slower performance groups[56].

A potential explanation for this finding could be that in marathons and half-marathons, low level runners are mainly slow and inexperienced runners[57]. In contrast, in this ultra-trail run, the low level runners probably consist of slow, but experienced runners who know how to pace themselves. We assume the same of the high level runners which pace consistent in every event[16]. We also found that the faster men's groups have more variability in pacing than the faster women's groups. This can possibly be explained by a faster start due to higher competitiveness. In the 'Spartathlon', male runners showed a significantly greater change in checkpoint speed at the first and second checkpoint of the race, while female runners showed a more significant change in checkpoint speed at the last checkpoint[36]. Similarly, in the fastest 'IRONMAN Hawaii' ever, the top athletes showed faster cycling and running split times, with differences in pacing strategies based on gender[40].

Limitations, implications for future research and practical applications

Some runners will rest or nap at checkpoints. It is difficult to determine how much time they spend at each checkpoint as this time is not really moving, and the actual running time between the checkpoints will be faster. Although we considered the influence of changes in elevation, the aspects of nutrition[58] and environmental conditions[59] could not be considered. In particular, the environmental conditions were not recored by the race organizers. Furthermore, environmental conditions change over a day and the runners are at different times in the race and therefore they have different conditions. Future studies might integrate physiological and psychological aspects in future models of pacing behaviour in ultra-marathon trail-running. For athletes and coaches, any athlete intending to compete in an ultra-marathon trail-run of this distance and with these changes in elevation might be aware that starting slow and trying to be steady in a race of this calibre would be the best option to reach the finish line safe.

Conclusions

Pacing in WSER-runners showed a great variability between checkpoints in both men and women. Pacing was positive and was influenced by elevation. Men started faster than women and men slowed down more than women. Pacing differed in male but not in female age group runners. The slowest and fastest ultra runners had less pacing variability than medium level runners. Athletes and coaches should be aware of these findings and focus on race preparation accordingly with adaptation of pacing.

Data availability

Data are available upon request from Beat Knechtle, beat.knechtle@hispeed.ch.

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Declarations

Competing interests

The authors declare no competing interests.

Additional information

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