PACING STRATEGIES IN MEN'S AND WOMEN'S WORLD-RECORD MARATHON PERFORMANCES AND OLYMPIC GAMES AND WORLD CHAMPIONSHIP'S WINNING PERFORMANCES

Arturo Casado[1], Luis E. Ranieri[1], José J. Díaz[2], Brian Hanley[3], and Carl Foster[4]

[1]Centre for Research in Sport Sciences, Rey Juan Carlos University, Madrid, Spain
[2]Epidemiology of Physical Activity and Fitness Across Lifespan, Universidad de Sevilla, Sevilla, Spain
[3]Carnegie School of Sports, Leeds Becket University, Leeds, United Kingdom
[4]Department Exercise and Sports Science, University of Wisconsin-La Crosse, La Crosse, WI, United States of America

Original scientific paper
DOI 10.26582/k.56.1.13

Abstract:

The aims of this study were to compare marathon pacing profiles between major championships winning races and world record (WR) races in men's and women's long-distance runners. Percentages of mean race speeds (%RS) for each 5 km section and last 2,195 m were compared between the latest 12 men's and 8 women's marathon WRs and the most recent 14 men's and 14 women's performances leading to either World Championship or Olympic Games (championships) gold medals, and between sexes in championships, through analysis of variance. Additionally, the coefficient of variation in pace (%CV) was compared through independent samples t-tests. %RS during the first 5 km was greater in WRs than championships in men (p=.010, d = 1.07), with a subsequent even pacing profile. More negative pacing profiles were adopted in championships than WRs in men (p< .001, d = 2.07). Women's WR and championship performances were characterized by even and negative pacing profiles, with different %CV (p<.001, d = 1.89). Whereas marathon WRs are characterized by fast, even and sustained paces, slower paces and more negative pacing approaches with fast endspurts are adopted during winning major championship performances. These fast endspurts are specially used by women in championships.

Keywords: *behavior, competition, endurance, running, tactics*

Introduction

An appropriate pacing strategy, defined as the regulation of exercise intensity and the way effort is distributed throughout an exercise task, is critical to achieving optimal performance by elite athletes (Foster, Schrager, Snyder, & Thompson, 1994). Pacing comprises a complex decision-making process that could be either beneficial or detrimental to individual performance (Renfree, Martin, Micklewright, & St Clair Gibson, 2014). Indeed, the specific problems faced by athletes in the competition are related to the distribution of available energy over a race (i.e., pacing behavior) and successful engagement in interpersonal competition (i.e., tactical ability) (Hanley, 2015) either when racing against the clock or against other competitors. Pacing and tactical behaviors have been found to be decisive factors in achieving high performance (Casado, Hanley, Jiménez-Reyes, & Renfree, 2021). More specifically, an optimized pacing strategy can improve performance in world-class marathoners (Angus, 2014). However, pacing behaviors differ according to the mode of exercise, event duration, knowledge and experience of the athlete and each opponent's physiological capacity (Casado, et al., 2021). In this regard, different pacing strategies are typically adopted by elite marathoners. Some of these profiles are negative, positive, and even pacing profiles (Casado, et al., 2021). A negative pacing profile is characterized by an increase in speed or power over the duration of the event. By contrast, a positive profile is characterized by a gradual decrease in speed or power throughout the duration of the event.

Contemporary marathon World Records (WRs) are characterized by a negative pacing pattern (Díaz, Fernández-Ozcorta, & Santos-Concejero, 2018), where the second half of the marathon is faster than the first. This is quite different from the "hitting the wall" pattern often seen in sub-elite runners, which is characterized by a decrease in speed from 35-38 km onwards due to the accumulated fatigue across the race (Muñoz-Pérez, Lago-Fuentes, Mecías-Calvo, & Casado, 2023). However, the pacing strategy adopted might be substantially different from that during major championship races. In championship races, the main objective is to achieve the best possible position. In regular competitions, such as big-city marathons, pacemakers are used to achieve the fastest possible winning performance during the event (Casado, et al., 2021). It is also important to choose wisely and join a running pack, adopting an initial non-excessive pace during the race to avoid a speed loss during its latest stages (Hanley, 2015). In addition, important sex-based differences in pacing strategy have been found during Olympic and World Athletics Championship marathons. Women typically slowed less during the race and were more likely to run a negative split than men (Hanley, 2016; Renfree & St Clair Gibson, 2013). Further, women's and men's marathoners have used an even or negative pacing profile, respectively, to break marathon WRs over the last 20 years (Díaz, Fernández-Ozcorta, Torres, & Santos-Concejero, 2019).

The differences between marathon pacing strategies during WR performances and major championships (i.e., World Championships and Olympic Games) have not been well studied. Better understanding of pacing during these major competitions could help athletes and coaches to optimize running strategies during different types of marathon races and to differentiate the training demands that are needed for the preparation of each type of race. Therefore, the aims of this study were twofold: to compare pacing profiles between: a) marathon major championships winning races (championships) and WR races in men and women, and 2) men and women in championships only, as this comparison was conducted previously in WRs (Díaz, et al., 2019). It was hypothesized that a slower pace with a faster endspurt (relative to the mean race pace) would be adopted during the championships vs. WR races. Additionally, a greater speed increase throughout the race was expected in women vs. men during championships.

Materials and methods

Design and data source

An observational design was carried out. Data were collected through a publicly accessible website (Association of Road Racing Statisticians [www.arrs.run website]), from which the official men's and women's marathon WRs were gathered. The official final and split times of championships were collected from the Hymans and Metrahazi database (Hymans, 2020) when available and from the World Athletics website (www.worldathletics.org [access date 10th October 2023]).

Methodology and participants

Twelve men's and eight women's marathon WRs, broken from 1998 to 2023, were analyzed. These eight women's WRs were paced by men's pacemakers. In turn, two other women's WRs were excluded from the analysis as they were not assisted by men's pacemakers. Regarding championships, 14 men's and 14 women's performances leading to either marathon World Championship or Olympic Games gold medals, achieved from 2001 to 2023, were analyzed. All WRs were performed between the 24th of September and until the 13th of April in the year they were achieved. By contrast, championships were held on dates between the 17th of July and until the 5th of October in their respective years. In addition, the unofficial sub-2 hours marathon performance achieved by Eliud Kipchoge in Vienna in October 2019 was also analyzed.

All section (i.e., split) times are defined both in terms of absolute speed ($m \cdot s^{-1}$) and as a percentage of the mean race speed (%RS). In addition, pace variation was analyzed using the coefficient of variation (%CV) of the race mean speed. For each athlete, the official final time and the time for each 5-km section were considered. The marathon distance was divided into eight sections of 5 km and a final, ninth, section of 2.195 km.

Statistical analysis

All data are presented as means and standard deviations (mean ± SD). Normal distribution and equality of variances were checked through the Shapiro-Wilk normality test and the Levene test, respectively. Assumption of sphericity was also checked through Mauchly's test, and Greenhouse-Geisser corrections were used if it was violated. Two-way analyses of variance (ANOVAs) with repeated measures with %RS as a between-section factor and sex (i.e., men or women) as a between-subjects factor were used to compare the pacing behavior between men and women in both WRs and championships. In addition, two-way repeated measures ANOVAs with absolute speed and %RS as a between-section factor and type of race (i.e., WR or championships) as a between-subjects factor were conducted to determine the pacing behaviors in the different race types. *Post-hoc* Tuckey corrections were performed in all pairwise comparisons, when justified by ANOVA. In addition, two independent samples *t*-tests were conducted to compare pacing strategies between WRs and championships in men and women, and between men's and women's championship- performances. An independent samples *t*-test was performed to compare %CV of pace between winning performances in championships and WRs in both sexes. Effect sizes were calculated through partial eta-squared for the repeated measures ANOVAs and Cohen's *d* (Cohen, 1988) for the Tukey *post-hoc* and *t*-student tests. Partial eta-squared was considered small (0.01), moderate (0.01–0.06) or large (> 0.15) (Cohen, 1988). Cohen's *d* was interpreted as small (≥ 0.2 and < 0.6), moderate (≥ 0.6 and < 1.2), large (≥ 1.2 and < 2.0) or very large (≥ 2.0 and < 4.0)((Hopkins, Marshall, Batterham, & Hanin, 2009)). The level of significance was defined at p<.05. IBM SPSS Statistics for Windows (Version 28.0 Armonk, NY: IBM Corp.) was used to analyze all data.

Results

Table 1 describes the section times of WRs analyzed in the present study. Table 2 describes the section times of the championships examined.

Figure 1 describes different pacing strategies adopted in the championship marathons and WRs among men and women in both % RS and absolute speed. Men's WRs were characterized by a faster first 5 km than those in championships (p=.01 *d*=1.07), with a subsequent even pacing profile during the rest of the race (Figure 1A). On the other hand, more negative pacing profiles were adopted during men's championships than men's WRs (Figure 1A and 1C). In this sense, %CV of the normalized speed was greater in men's championships than in WRs (2.91 ± 0.75 % vs. 1.52 ± 0.54%, p<.001 *d* = 2.07), showing that championship performance displayed a wider variation of pace. Men's WRs were run at a faster speed throughout the race than championships (Figure 1C).

Significant differences in normalized or absolute speed with at least moderate effect size between global championship winning performances and world records within each section are indicated as $^{\#}$ p<.05 with moderate effect; $^{\#\#}$ p<.05 with large effect; * p<.001 with moderate effect; ** p<.001 with large effect; *** p<.001 with very large effect. Significant variation across sections in women's global championship performances are indicated as & (p<.001 with small effect) and as $ in men's world records (p=.006 with small effect).

Women's WR and championship performances were characterized by even and negative pacing profiles, respectively (Figures 1B and 1D). Thus, championships also showed a wider variation of pace than WRs (%CV = 3.18 ± 0.88 % vs. 1.61 ± 0.72%, p<.001, *d* = 1.89). During the last 7.195 km, a faster normalized speed was observed in

Table 1. Final and section times of men's and women's marathon world records broken from 1998 to 2023

Athlete (men and women)	City and year	Final time (h:min:s)	Section (km) and speed (m/s)								
			0-5	*5-10*	*10-15*	*15-20*	*20-25*	*25-30*	*30-35*	*35-40*	*40-end*
R. da Costa	Berlin 1998	2:06:05	5.43	5.45	5.41	5.47	5.68	5.71	5.68	5.68	5.93
K. Khannouchi	Chicago 1999	2:05:42	5.50	5.64	5.62	5.64	5.51	5.56	5.69	5.55	5.73
K. Khannouchi	London 2002	2:05:38	5.66	5.60	5.57	5.57	5.70	5.61	5.57	5.48	5.67
P. Tergat	Berlin 2003	2:04:55	5.55	5.57	5.62	5.57	5.57	5.67	5.71	5.69	5.82
H. Gebrelassie	Berlin 2007	2:04:26	5.66	5.66	5.62	5.59	5.59	5.61	5.66	5.75	5.84
H. Gebrelassie	Berlin 2008	2:03:59	5.71	5.69	5.62	5.64	5.61	5.64	5.69	5.75	5.70
P. Makau	Berlin 2011	2:03:38	5.70	5.68	5.71	5.69	5.63	5.81	5.69	5.56	5.73
W. Kipsang	Berlin 2013	2:03:23	5.73	5.66	5.75	5.71	5.60	5.63	5.71	5.71	5.92
D. Kimetto	Berlin 2014	2:02:57	5.67	5.67	5.64	5.77	5.73	5.75	5.89	5.67	5.66
E. Kipchoge	Berlin 2018	2:01:39	5.79	5.70	5.70	5.81	5.76	5.81	5.83	5.75	5.98
E. Kipchoge	Berlin 2022	2:01:09	5.85	5.89	5.88	5.87	5.79	5.73	5.75	5.66	5.84
K. Kiptum	Chicago 2023	2:00:35	5.77	5.84	5.77	5.75	5.78	5.77	6.02	5.95	5.90
T. Loroupe	Rotterdam 1998	2:20:47	5.03	5.03	5.05	4.98	4.91	5.02	5.03	4.92	5.02
T. Loroupe	Berlin 1999	2:20:43	5.10	5.14	5.00	4.94	4.85	4.79	5.06	5.07	5.10
N. Takahashi	Berlin 2001	2:19:46	4.71	5.06	5.05	5.18	5.19	5.13	5.12	5.08	5.20
C. Ndereba	Chicago 2001	2:18:47	4.98	5.08	5.07	5.03	5.11	5.04	5.07	5.00	4.81
P. Radcliffe	Chicago 2002	2:17:18	5.05	5.12	5.11	5.10	5.17	5.18	5.18	5.09	5.10
P. Radcliffe	London 2003	2:15:25	5.27	5.14	5.13	5.14	5.18	5.20	5.22	5.24	5.28
B. Kosgei	Chicago 2019	2:14:04	5.39	5.21	5.22	5.20	5.18	5.29	5.23	5.22	5.31
T. Assefa	Berlin 2023	2:11:53	5.21	5.29	5.31	5.40	5.27	5.36	5.38	5.36	5.49

Table 2. Final and section times of women's and men's marathon global championship (World Championships [WCh] and Olympic Games [OG]) winning performances achieved from 2001 to 2023

Athlete (men and women)	City, type of race and year	Final time (h:min:s)	Section (km) and speed (m/s)								
			0-5	*5-10*	*10-15*	*15-20*	*20-25*	*25-30*	*30-35*	*35-40*	*40-end*
G. Abera	Edmonton WCh 2001	2:12:42	5.25	5.39	5.13	5.24	5.28	5.30	5.29	5.41	5.61
J. Gharib	Paris WCh 2003	2:08:31	5.52	5.46	5.43	5.24	5.37	5.41	5.66	5.62	5.69
J. Gharib	Helsinki WCh 2005	2:10:10	5.43	5.54	5.48	5.40	5.36	5.48	5.46	5.22	5.07
A. Kirui	Berlin WCh 2009	2:06:54	5.49	5.56	5.62	5.66	5.58	5.52	5.48	5.47	5.43
A. Kirui	Daegu WCh 2011	2:07:38	5.22	5.42	5.51	5.47	5.66	5.83	5.68	5.46	5.23
S. Kiprotich	London OG 2012	2:08:01	5.42	5.42	5.77	5.56	5.60	5.49	5.27	5.51	5.37
S. Kiprotich	Moscow WCh 2013	2:09:51	5.24	5.34	5.51	5.49	5.42	5.41	5.42	5.42	5.66
G. Ghebreslassie	Beijing WCh 2015	2:12:28	5.16	5.30	5.21	5.35	5.24	5.20	5.42	5.60	5.39
E. Kipchoge	Rio OG 2016	2:08:44	5.37	5.33	5.30	5.35	5.29	5.54	5.78	5.66	5.78
G. K. Kirui	London WCh 2017	2:08:27	5.21	5.34	5.43	5.45	5.76	5.65	5.66	5.41	5.34
L. Desisa	Doha WCh 2019	2:10:40	5.17	5.36	5.22	5.52	5.59	5.35	5.34	5.35	5.85
E. Kipchoge	Tokyo OG 2020	2:08:38	5.44	5.35	5.49	5.30	5.34	5.51	5.76	5.58	5.45
T. Tola	Eugene WCh 2022	2:05:36	5.30	5.50	5.55	5.56	5.45	5.57	5.88	5.89	6.00
V. Kiplangat	Budapest WCh 2023	2:08:53	5.35	5.54	5.36	5.40	5.39	5.50	5.69	5.56	5.21
L. Simon	Edmonton WCh 2001	2:26:01	4.63	4.82	4.68	4.82	5.01	4.60	4.91	4.99	5.08
C. Ndereba	Paris WCh 2003	2:23:55	4.81	4.92	4.88	4.72	4.75	4.78	4.97	5.22	5.10
P. Radcliffe	Helsinki WCh 2005	2:20:57	4.97	5.02	5.05	5.14	5.00	5.03	4.94	4.86	4.82
C. Ndereba	Osaka WCh 2007	2:30:37	4.49	4.66	4.61	4.60	4.57	4.72	4.71	4.78	5.23
X. Bai	Berlin WCh 2009	2:25:15	4.70	4.80	4.87	4.73	4.70	4.90	5.05	4.87	5.16
T. Gelana	London OG 2012	2:23:07	4.81	4.78	4.79	4.82	4.93	5.10	4.98	5.00	5.26
E. N. Kiplagat	Moscow WCh 2013	2:25:44	4.81	4.80	4.98	4.73	4.74	4.79	4.88	4.83	4.97
M. Dibaba	Beijing WCh 2015	2:27:35	4.66	4.72	4.67	4.64	4.64	4.74	4.84	5.03	5.26
J. J. Sumgong	Rio OG 2016	2:24:04	4.79	4.91	4.80	4.79	4.90	4.84	4.85	5.05	5.20
R. Chelimo	London WCh 2017	2:27:11	4.63	4.71	4.68	4.74	4.84	4.74	4.65	5.10	5.18
R. Chepngetich	Doha WCh 2019	2:32:43	4.54	4.53	4.82	4.49	4.52	4.58	4.59	4.77	4.66
P. Jepchirchir	Tokyo OG 2020	2:27:20	4.62	4.57	4.75	4.72	4.79	4.84	4.93	4.90	4.98
G. Gebresalase	Eugene WCh 2022	2:18:11	5.15	5.06	4.95	5.17	5.06	5.18	5.04	5.02	5.30
A.B. Shankule	Budapest WCh 2023	2:24:23	4.66	4.72	4.79	4.72	4.83	5.02	5.17	5.13	4.85

championships than in WRs (Figure 1B). Women's WRs were faster than championships during every section apart from the last 2.195 km (Figure 1D). Moreover, women's championship performances were faster during the last 2.195 km than the first 5 km ($p<.001$).

Figure 2A describes the percentage of normalized speed during each section of men's and women's championship marathon performances. Although both men's and women's championship marathoners displayed an even pace during most of the race, women were able to generate a relatively faster endspurt than men ($p=.029$, $d = 0.62$).

Both men's (Figure 2B) and women's (Figure 2C) normalized speeds (%) during each section and finishing times of the current marathon WRs and Tokyo 2020 Olympic Games are indicated in Figure 2. Additionally, normalized speeds (%) during each section and finishing time of the only marathon performance covered in less than two hours are indicated in Figure 2B. Kenyan runner Kelvin Kiptum adopted an even pacing strategy with a fast endspurt from the 30th to the 35th km of the race to break the current WR by the time of writing (Figure 2B). Furthermore, the strategy to break the two hours barrier during an unofficial race by the

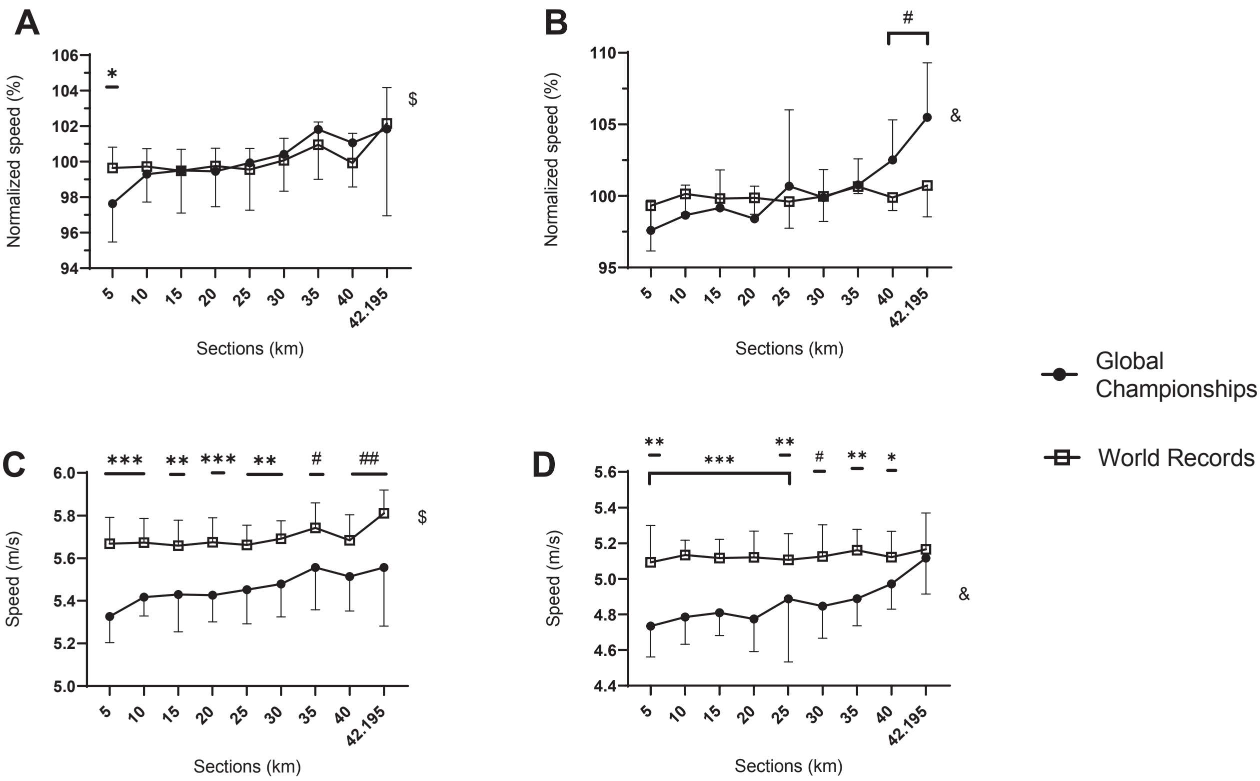

Figure 1. Differences in marathon normalized mean speed and absolute mean speed within each race section between global championship winning performances and world records in men (A and C) and women (B and D) and pace variation across sections in each type of race.

Kenyan Eliud Kipchoge, was even more even than that used to break the current WR, and also was characterized by an endspurt (Figure 2B). However, Kipchoge displayed greater fluctuations of speeds with a remarkable acceleration from the 25th to the 35th km to break away from the field and win the Tokyo 2020 Olympic Games marathon (Figure 2B). Negative and even pacing profiles characterized women's performances at the Tokyo 2020 Olympic Games by Kenyan runner Peres Jepchirchir and the current marathon WR set in the Berlin Marathon 2023 by the Ethiopian Tigist Assefa, respectively (Figure 2C).

Discussion and conclusions

The main aims of the present study were to compare recent championships (World Athletics Championships and Olympic Games) and WR marathon pacing strategies in men and women and to do so between sexes during championship performances. This is the first study directly comparing marathon pacing strategies between WRs and performances achieved during major championships. In agreement with our hypothesis, a more negative profile was displayed in championships than in WRs in both men and women. In this regard, the current data suggest that contemporary elite-standard marathons are more similar to long distance track races than to those covered by recreational runners which are characterized by a progressively slowing pace (e.g., hitting the wall) (Smyth, 2021).

The fact that none of the WRs analyzed were set during any major recent championship race (Tables 1 and 2) agrees with some of the present findings. For example, during the latest stages of WRs, when pacemakers cannot help WR performers because they have dropped out of the race, the absolute speed was similar and faster than that in championships in women (Figure 1D) and men (Figure 1C), respectively. That means that even despite having run much slower than WRs during almost the whole race (Figures 1C and 1D) and having to be as fast as possible during the last endspurt to win (Hanley, 2016; Renfree & St Clair Gibson, 2013), women's championship marathoners were not able to run faster than their counterparts breaking a WR during the last 2.195 km (Figure 1D), and men's championship runners did so even slower (Figure 1C). Therefore, these important speed differences among these types of races cannot only be explained by the different runners' aims or goals at each type of race (i.e., achieving the fastest mean speed during WRs vs. the highest finishing position during championships [Casado, et al., 2021]). Rather, the phenomenon explaining these differences should be considered multifactorial and is determined by several variables such as weather, the

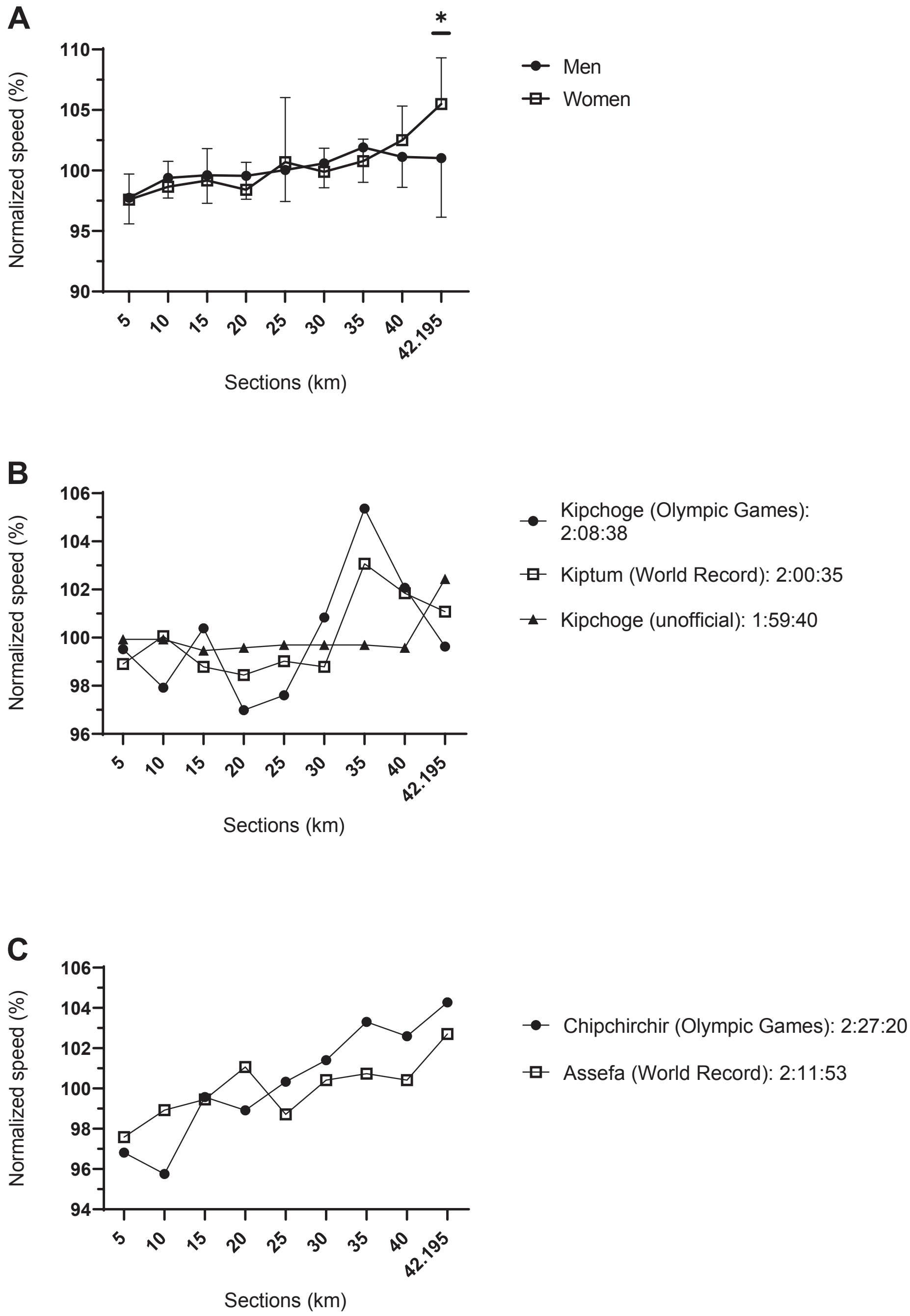

*Figure 2. Mean and standard deviation of normalized speed in men's and women's winning performances during the different sections of global championship marathons (A), and final times indicated as h:min:s and normalized speeds at each section of marathon Tokyo 2020 Olympic gold performances (Eliud Kipchoge [B] and Peres Jepchirchir [C]), current marathon world records (Kelvin Kiptum [B] and Tigist Assefa [C]) at the time of writing, and sub 2-hours race performed in Vienna 2019 (Kipchoge [B]). * Significant difference (p<.05) with moderate effect between sexes.*

help provided by pacemakers, runners' objectives, and course elevation. First, major championships are typically held during the warmest months of the year excepting some other 'hot' and 'humid' countries like Brazil or Qatar where these characteristics remain constant all year round. For example, very high temperatures and humidity were considered the major causes of marathon performance deterioration during the 2019 Doha World Championships in the women's race. In addition, 41% of the women's athletes taking part in this race did not finish, presumably due to weather issues (Beal, Corbett, Davis, & Barwood, 2022). In this sense, this negative influence of heat on marathon running performance leads to a greater slowing (Beal, et al., 2022) compared to cooler conditions might rely on thermoregulatory disturbances such as increased pulmonary ventilation and cardiovascular strain, and alterations in brain function, muscle metabolism and central fatigue (Gonzalez-Alonso, 2007; Nybo, Rasmussen, & Sawka, 2014). All WRs analyzed have been broken during the autumn (fall), winter or spring at the locations where those races were held.

On the other hand, pacing behaviors can also be impacted by drafting. Drafting influences positively on performance in distance running events (Casado, Moreno-Pérez, Larrosa, & Renfree, 2019). Accordingly, a reduction of almost 5.9% in the metabolic cost of running could be derived from running behind another athlete during the second half of a marathon (Hoogkamer, Snyder, & Arellano, 2018). The specific influence of drafting is particularly important during WR performances, in contrast to championships. They are typically assisted by pacemakers who are expected to set a preassigned pace near the anticipated limit of the best runners throughout the race (Hanley, 2016). Therefore, apart from the faster absolute overall speed in WRs than in championships, the assistance provided by pacemakers could also partially explain the faster percentage of normalized speed during the first 5 km of WR races in men and the more even pacing profile set by men and women in WRs vs. championship marathons. It also may explain the greater performance and more even pacing strategy in the only (unofficial) marathon run covered under two hours and the current men's WR (Figure 2B), being achieved by Kipchoge and Kiptum, respectively. These differences may mainly be explained by the assistance of rotating pacemakers in the former until almost the end the race. The other important factor that could differentiate the pacing profile observed within each type of race is the distinct goal of the athlete. Whereas championship runners usually establish a slow pace during the early stages to ultimately be able to generate a fast endspurt and achieve the highest finishing position, WR contenders prefer to adopt the evenest pace throughout the race to achieve the fastest mean speed (Díaz, et al., 2019). Furthermore, Casado, Ranieri, Hanley, Foster, & González-Mohíno (2024) found similar pacing trends in middle-and long-distance track WRs, and Olympic and World Championship medal performances, displaying more even and negative pacing profiles, respectively.

Further, in agreement with our hypothesis, women's championship races displayed a more negative pacing behavior than men's championship races did (Figure 2A). Accordingly, women's championships were characterized by the completion of a prolonged, fast endspurt. These outcomes support those of Hanley (2016), who reported that whereas women's Olympic Games and World Championship marathon medalists did not slow down during the later stages of the race, their male counterparts did. However, in contrast to the present study, Hanley (2016) did not directly compare pacing behaviors between sexes. Furthermore, the faster percentage of normalized speed displayed by women in championships between the final 2.195 km and the first 5 km also emphasizes the negative profile performed by these athletes.

Differences in pacing strategies between sexes might depend on physiological, hormonal, and decision-making factors (Deaner, Carter, Joyner, & Hunter, 2014). Indeed, whereas men are more susceptible to glycogen depletion, which can contribute to a considerable slowing and greater fatigue, women display a lower and greater rate of carbohydrate and amino acid, and fat oxidation, respectively, during submaximal endurance exercise than men (Rapoport, 2010). These differences might be caused by 17-β-estradiol in women (Tarnopolsky, 2008).

Additionally, women possess a greater proportional area of 'slow' type I fibers, which are more resistant to fatigue, especially in long-duration exercise, in several muscles that are essential for locomotion (Hunter, 2014). Studies of non-elite runners suggest that men are more likely to slow their marathon pace than women (Deaner, et al., 2014). Therefore, the combination of these factors could confer women greater physiological, hormonal, and tactical abilities that could allow them to generate a relatively faster and prolonged endspurt during the latest stages of the race (Figure 2A).

Pacing behaviors leading to both current men's and women's Olympic marathon gold medals displayed a greater variation of pace than those leading to current men's and women's marathon WRs (Figure 2B and 2C). Similarly, Foster, De Koning, & Thiel (2014) found that the faster the mile world records, the lower the variability in pacing behavior (Foster, et al., 2014). However, whereas both WRs adopted an even pacing strategy with a fast endspurt, reigning men's Olympic champion Eliud Kipchoge (at the time of writing) slowed during the final stages of the race to earn his gold medal, although he had a very fast mid-race 10-km to break away from the field. The reigning women's Olympic champion Peres Jepchirchir generated a fast endspurt to win her Championship (Figure 2B and 2C). These endspurts observed during both WRs, the sub-two hours marathon performance, and championships could be partially explained by the assistance of the use of new shoe technology based on specifically positioned carbon fiber plate and foam cushioning (Muniz-Pardos, et al., 2021), which showed improvements in both performance and running economy (Hébert-Losier, et al., 2022). The use of this technology might decrease muscular fatigue throughout the marathon (Muniz-Pardos, et al., 2021), and therefore contribute to the fast speeds achieved during the later stages. In addition, the ability to accelerate until the finish line after covering more than 35 km at a sustained and relatively fast speed might be explained by the development of the specific physiological determinants in this type of long endurance race. In this way, Jones et al. (2021) found that the only marathoner who had been able to run 42.195 km in under 2 hours until the time of writing the present article, Eliud Kipchoge, displayed remarkable values of running economy (Jones, et al., 2021) (i.e., energy cost at a submaximal and constant intensity (Foster & Lucia, 2007). Furthermore, durability (i.e., the time of onset and magnitude of deterioration in physiological-profiling characteristics over time during a prolonged exercise) has been recently considered as one of the endurance physiological performance determinants, especially in longer events such as the marathon (Maunder, Seiler, Mildenhall, Kilding, & Plews, 2021). Therefore, high levels of both running economy and durability may be behind of these remarkable marathon performances and their typical endspurts.

Championship racing featured a more negative pacing profile than that followed by WRs in men and women. Women's championship races displayed a more negative pacing profile than the men's equivalent races. In this sense, women's championships involved a prolonged and fast endspurt during the later stages of the race. Performances by current men's and women's marathon Olympic and World Championship gold medalists displayed a greater pace variation than that of the current men's and women's WRs at the time of writing. WRs were faster than championships across the whole race in both men and women. These differences could be related to the fact that most WRs were set during cooler months than those when championships were held, and to the benefits of pacemakers during WRs.

One limitation should be acknowledged in the present study. Pacing characteristics were analyzed using five km split times, which are too long and thus cannot fully explain the pacing behavior adopted by runners across the whole marathon.

Practical applications

Breaking a marathon WR requires the adoption of a basically even pace, avoiding, as much as possible, variation of pace across the race. In this sense, the initial speed of pacemakers during the race should be very carefully selected according to the specific abilities of the WR contender (i.e., performance in recent races and training performance during recent training sessions) and the specific time target which is dependent on the current WR. Excessively fast early paces may result in a further slowing that would prevent optimal performance and, therefore, prevent achieving a WR. In addition, climate conditions and course profile should be optimal to break a marathon WR. In effect, minimal changes in course elevation are required and air temperatures between 13°C and 18°C (Scheer, et al., 2021). On the other hand, marathon training specifically designed to be able to perform a negative pacing strategy might be necessary to win a championship marathon such as at the Olympic Games or World Athletics Championships. However, whereas women might need to develop the ability to generate a very fast and prolonged endspurt, men seem to be required to sustain a fairly fast pace from halfway onwards. These different abilities needed may in turn be optimally developed through different training approaches according to sex.

Future perspectives

Future studies could focus on the analysis of different psychophysiological responses to training and racing between men's and women's elite marathoners, which in turn could explain their different pacing behaviors during these world-class races. In addition, future studies should try to assess the pack formations typically adopted during marathon WRs, and not only during championships (Hanley, 2016), which may elucidate the differences in pacing behavior between men and women. Finally, future research could try to determine whether training strategies in elite marathoners that specifically target adaptations to achieve a negative pacing profile are more effective than those targeting the achievement of the fastest mean speed across the race, and vice versa.

References

Angus, S.D. (2014). Did recent world record marathon runners employ optimal pacing strategies? *Journal of Sports Sciences*, *32*(1), 31-45. https://doi.org/10.1080/02640414.2013.803592

Beal, H., Corbett, J., Davis, D., & Barwood, M. J. (2022). Marathon Performance and Pacing in the Doha 2019 Women's IAAF World Championships: Extreme Heat, Suboptimal Pacing, and High Failure Rates. *International Journal of Sports Physiology and Performance*, *17*(7), 1119–1125. https://doi.org/10.1123/ijspp.2022-0020

Casado, A., Hanley, B., Jiménez-Reyes, P., & Renfree, A. (2021). Pacing profiles and tactical behaviors of elite runners. *Journal of Sport and Health Science*, *10*(5), 537-549. https://doi.org/10.1016/j.jshs.2020.06.011

Casado, A., Moreno-Pérez, D., Larrosa, M., & Renfree, A. (2019). Different psychophysiological responses to a high-intensity repetition session performed alone or in a group by elite middle-distance runners. *European Journal of Sport Science*, *19*(8), 1045-1052. https://doi.org/10.1080/17461391.2019.1593510

Casado, A., Ranieri, L.E., Hanley, B., Foster, C., & González-Mohíno, F. (2024). Differences in pacing behaviour between global championship medal performances and world records in men's and women's middle- and long-distance running track events. *Journal of Sports Sciences*, *42*(4), 358-364. https://doi.org/10.1080/02640414.2024.2330819

Cohen, J. (1988). *Statistical power analysis* (2nd ed.). Hillsdale, NJ: Erlbaum.

Deaner, R.O., Carter, R.E., Joyner, M.J., & Hunter, S.K. (2014). Men are more likely than women to slow in the marathon. *Medicine and Science in Sports and Exercise*, *47*(3), 607-616. https://doi.org/10.1249/MSS.0000000000000432

Díaz, J.J., Fernández-Ozcorta, E.J., & Santos-Concejero, J. (2018). The influence of pacing strategy on marathon world records. *European Journal of Sport Science*, *18*(6), 781-786. https://doi.org/10.1080/17461391.2018.1450899

Díaz, J.J., Fernández-Ozcorta, E.J., Torres, M., & Santos-Concejero, J. (2019). Men vs. women world marathon records' pacing strategies from 1998 to 2018. *European Journal of Sport Science*, *19*(10), 1297-1302. https://doi.org/10.1080/17461391.2019.1596165

Foster, C., De Koning, J.J., & Thiel, C. (2014). Evolutionary pattern of improved 1-mile running performance. *International Journal of Sports Physiology and Performance*, *9*(4), 715-719. https://doi.org/10.1123/IJSPP.2013-0318

Foster, C., & Lucia, A. (2007). Running economy: The forgotten factor in elite performance. *Sports Medicine*, *37*(4), 316-319. https://doi.org/10.2165/00007256-200737040-00011

Foster, C., Schrager, M., Snyder, A.C., & Thompson, N.N. (1994). pacing strategy and athletic performance. *Sports Medicine*, *17*(2), 77-85. https://doi.org/10.2165/00007256-199417020-00001

Gonzalez-Alonso, J. (2007). Hyperthermia impairs brain, heart and muscle function in exercising humans. *Sports Medicine*, *37*(4), 371-373. https://doi.org/10.2165/00007256-200737040-00025

Hanley, B. (2015). Pacing profiles and pack running at the IAAF World Half Marathon Championships. *Journal of Sports Sciences*, *33*(11), 1189-1195. https://doi.org/10.1080/02640414.2014.988742

Hanley, B. (2016). Pacing, packing and sex-based differences in Olympic and IAAF World Championship marathons. *Journal of Sports Sciences*, *34*(17), 1675-1681. https://doi.org/10.1080/02640414.2015.1132841

Hébert-Losier, K., Finlayson, S.J., Driller, M.W., Dubois, B., Esculier, J.F., & Beaven, C.M. (2022). Metabolic and performance responses of male runners wearing 3 types of footwear: Nike Vaporfly 4%, Saucony Endorphin racing flats, and their own shoes. *Journal of Sport and Health Science*, *11*(3), 275-284. https://doi.org/10.1016/j.jshs.2020.11.012

Hoogkamer, W., Snyder, K.L., & Arellano, C.J. (2018). Modeling the benefits of cooperative drafting: Is there an optimal strategy to facilitate a sub-2-hour marathon performance? *Sports Medicine*, *48*(12), 2859-2867. https://doi.org/10.1007/s40279-018-0991-4

Hopkins, W.G., Marshall, S.W., Batterham, A.M., & Hanin, J. (2009). Progressive statistics for studies in sports medicine and exercise science. *Medicine and Science in Sports and Exercise*, *41*(1), 3-13. https://doi.org/10.1249/MSS.0b013e31818cb278

Hunter, S.K. (2014). Sex differences in human fatigability: Mechanisms and insight to physiological responses. *Acta Physiologica*, *210*(4), 768-789. https://doi.org/10.1111/apha.12234

Hymans, R. (2020). *Progression of IAAF World Records*. IAAF Athletics. https://media.aws.iaaf.org/misc/eBook/index.html#page=1

Jones, A.M., Kirby, B.S., Clark, I.E., Rice, H.M., Fulkerson, E., Wylie, L.J., Wilkerson, D.P., Vanhatalo, A., & Wilkins, B.W. (2021). Physiological demands of running at 2-hour marathon race pace. *Journal of Applied Physiology*, *130*(2), 369-379. https://doi.org/10.1152/JAPPLPHYSIOL.00647.2020

Maunder, E., Seiler, S., Mildenhall, M.J., Kilding, A.E., & Plews, D.J. (2021). The importance of 'durability' in the physiological profiling of endurance athletes. *Sports Medicine*, *51*(8), 1619-1628. https://doi.org/10.1007/s40279-021-01459-0

Muniz-Pardos, B., Sutehall, S., Angeloudis, K., Guppy, F.M., Bosch, A., & Pitsiladis, Y. (2021). Recent improvements in marathon run times are likely technological, not physiological. *Sports Medicine*, *51*(3), 371-378. https://doi.org/10.1007/s40279-020-01420-7

Muñoz-Pérez, I., Lago-Fuentes, C., Mecías-Calvo, M., & Casado, A. (2023). Pacing and packing behaviour in elite and world record performances at Berlin marathon. *European Journal of Sport Science*, *23*(8), 1472-1479. https://doi.org/10.1080/17461391.2022.2111278

Nybo, L., Rasmussen, P., & Sawka, M.N. (2014). Performance in the heat—physiological factors of importance for hyperthermia-induced fatigue. *Comprehensive Physiology*, 4(2), 657-689). Wiley. https://doi.org/10.1002/cphy.c130012

Rapoport, B.I. (2010). Metabolic factors limiting performance in marathon runners. *PLoS Computational Biology*, *6*(10), e1000960. https://doi.org/10.1371/journal.pcbi.1000960

Renfree, A., Martin, L., Micklewright, D., & St Clair Gibson, A. (2014). Application of decision-making theory to the regulation of muscular work rate during self-paced competitive endurance activity. *Sports Medicine*, 44(2), 147-158. https://doi.org/10.1007/s40279-013-0107-0

Renfree, A., & St Clair Gibson, A. (2013). Influence of different performance levels on pacing strategy during the Women's World Championship marathon race. *International Journal of Sports Physiology and Performance*, *8*(3), 279-285. https://doi.org/10.1123/ijspp.8.3.279

Scheer, V., Valero, D., Villiger, E., Alvero Cruz, J.R., Rosemann, T., & Knechtle, B. (2021). The optimal ambient conditions for world record and world class performances at the Berlin marathon. *Frontiers in Physiology*, *12*, 654860. https://doi.org/10.3389/fphys.2021.654860

Smyth, B. (2021). How recreational marathon runners hit the wall: A large-scale data analysis of late-race pacing collapse in the marathon. *PloS One*, *16*(5), e0251513. https://doi.org/10.1371/journal.pone.0251513

Tarnopolsky, M.A. (2008). Sex differences in exercise metabolism and the role of 17-beta estradiol. *Medicine and Science in Sports and Exercise*, *40*(4), 648-654. https://doi.org/10.1249/MSS.0b013e31816212ff

Submitted: April 12, 2024
Accepted: June 20, 2024
Published Online First: June 27, 2024

Correspondence to:
Luis E. Ranieri, Ph.D. candidate
Centre for Research in Sport Sciences
Rey Juan Carlos University
Cam. del Molino, 5, 28943 Fuenlabrada, Madrid, Spain
Phone: +34 611594151
E-mail: le.ranieri.2022@alumnos.urjc.es

Funding: This research was funded by the Erasmus + Program during the L.E.R. traineeship period of 2021/2022, approved by the EU Regulation n. 1288/2013 of the European Parliament and the Council of December 11, 2013 - Notes n. 2/2020 on 11/03/2020 and n. 3/2020 on 03/04/2020 of the National Agency Eramsus+ Indire. The Erasmus Traineeship Announcement 2021/22 is Rector's Decree No. 233/2022 dated 19/01/2022.

Data availability statement: The data used for this study are in the public domain. The data and materials are available to interested researchers upon request.

Conflicts of interest: The authors declare no conflicts of interest.