Men Are More Likely than Women to Slow in the Marathon

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[1]Department of Psychology, Grand Valley State University, Allendale, MI; [2]Department of Health Sciences Research, Mayo Clinic, Rochester, MN; [3]Department of Anesthesiology, Mayo Clinic, Rochester, MN; and [4]Exercise Science Program, Department of Physical Therapy, Marquette University, Milwaukee, WI

ABSTRACT

DEANER, R. O., R. E. CARTER, M. J. JOYNER, and S. K. HUNTER. Men Are More Likely than Women to Slow in the Marathon. *Med. Sci. Sports Exerc.*, Vol. 47, No. 3, pp. 607–616, 2015. Studies on nonelite distance runners suggest that men are more likely than women to slow their pace in a marathon. **Purpose**: This study determined the reliability of the sex difference in pacing across many marathons and after adjusting women's performances by 12% to address men's greater maximal oxygen uptake and also incorporating information on racing experience. **Methods**: Data were acquired from 14 US marathons in 2011 and encompassed 91,929 performances. For 2929 runners, we obtained experience data from a race-aggregating Web site. We operationalized pace maintenance as the percentage change in pace observed in the second half of the marathon relative to the first half. Pace maintenance was analyzed as a continuous variable and as two categorical variables, as follows: "maintain the pace," defined as slowing <10%, and "marked slowing," defined as slowing ≥30%. **Results**: The mean change in pace was 15.6% and 11.7% for men and women, respectively ($P < 0.0001$). This sex difference was significant for all 14 marathons. The odds for women were 1.46 (95% confidence interval, 1.41–1.50; $P < 0.0001$) times higher than men to maintain the pace and 0.36 (95% confidence interval, 0.34–0.38; $P < 0.0001$) times that of men to exhibit marked slowing. Slower finishing times were associated with greater slowing, especially in men (interaction, $P < 0.0001$). However, the sex difference in pacing occurred across age and finishing time groups. Making the 12% adjustment to women's performances lessened the magnitude of the sex difference in pacing but not its occurrence. Although greater experience was associated with less slowing, controlling for the experience variables did not eliminate the sex difference in pacing. **Conclusions**: The sex difference in pacing is robust. It may reflect sex differences in physiology, decision making, or both. **Key Words**: GENDER, DISTANCE RUNNING, RISK TAKING, ENDURANCE EXERCISE, EXPERIENCE, SUBSTRATE USE

Pacing in endurance races has long been of interest to sports scientists, but research has been traditionally limited to elite or subelite athletes (1,13,28,37). The recent availability of data from mass-participation events, however, has permitted pacing to be investigated in a broader range of athletes, including nonelite distance runners. Several notable patterns have emerged, including that men are more likely than women to slow their pace in the marathon (42.195 km) (26,35).

The sex difference in pacing could reflect physiological differences, such as men's greater susceptibility to muscle glycogen depletion (7,31,34) or women's skeletal muscle showing less fatigability (19). An alternative, but compatible, possibility is that pacing differences may reflect decision making (2). In particular, men may be more likely to adopt a "risky" pace, where an individual begins the race with a fast early pace (relative to their ability), and this increases their likelihood of slowing later. If either of these possibilities proved correct, they would constitute a novel source of pacing variation, one that has not been considered in studies on elite or subelite athletes.

Here, we addressed the robustness of the sex difference in marathon pacing by extending previous studies in three ways. First, rather than focusing on one marathon, we evaluated a sample of 14 marathons, which encompasses data from over 91,000 performances. This allowed us to generalize our findings to a range of ages and a variety of races.

Second, we obtained information on racing experience for a subsample of participants (>2900) and tested whether experience was related to pacing and whether it might contribute to the (possible) sex difference in pacing. A previous study reported that older runners showed more even marathon pacing and suggested that this reflected their greater racing experience (26). However, no previous study has directly tested whether race experience is associated with better pacing.

Third, we made a 12% adjustment or correction to women's performances to address the fact that they are roughly 10%–12% slower than men's even when training and talents are

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similar (8,20,21,24,32). This sex difference reflects men's greater maximal oxygen uptake ($\dot{V}O_{2max}$), which is mediated by their larger hearts, greater hemoglobin concentration, less body fat, and greater muscle mass per unit of body weight (8,20,21,24,32). Making this adjustment allows the alignment of relative performance between the sexes. This is potentially important because, at least in some populations (e.g., older runners), a larger proportion of men than women achieves relatively fast performances (11,20,21) and relatively fast performances may, in turn, be associated with more even pacing (26). In other words, the previously reported sex difference in pacing (26,35) might merely reflect that more men than women run relatively fast.

Although most of our analyses are based on making a 12% adjustment to women's performances, we also explored other adjustments. We used a 10% adjustment to address the commonly mentioned lower bound for the sex difference in $\dot{V}O_{2max}$ (8,19,22,26,34) and the 10% difference we observed in the mean finishing times for men and women in our sample. We used a 16% adjustment because the sex difference in endurance performance, although typically approximately 10% for world records and other leading performances, is often observed to be 14%–16% for near-elite performers (11,20,32). Finally, to allow direct comparisons with previous studies (2,28,37), we conducted analyses without any adjustment.

The purpose of this study, therefore, was to compare the pacing or pace maintenance (duration of the first half of the marathon relative to the second half) of men and women across different age groups and abilities (finishing times) in a large sample of marathons. A secondary purpose was to determine whether racing experience was related to pacing and whether it might contribute to the sex difference in pacing. A third purpose was to test whether adjusting women's performances to account for their lower $\dot{V}O_{2max}$ would affect the sex difference in pacing.

METHODS

This study did not require formal approval by Grand Valley State's institutional review board (IRB) or the other IRB (Marquette University, Mayo Clinic). The Grand Valley State University IRB determined that the protocol (reference number 14-078-H) was exempt under federal category 45 CFR 46.101(b) (4) because all data were preexisting and public.

We began identifying potential marathons using marathon.guide.com, a Web site that attempts to maintain a comprehensive list. We initially considered all 75 marathons with more than 1000 finishers held in the United States in 2011. We discovered, however, that many races did not provide halfway times, and, among those races that did, data were often difficult to download efficiently. We therefore focused on the 14 races where halfway and full race data were presented with the active.com timing platform, which permitted efficient data acquisition.

Of the 96,774 individual times available, the final analysis set consisted of 91,929 (95%) usable finishing times. Criteria for inclusion in the final data set were having timing data for the halfway mark and the full race in proper sequence (e.g., finishing time greater than half marathon time), a net time less than the gun time, and a slowing less than 400%. The number of participants by marathon is presented in Table 1. The sample consisted of 41.5% women ($n = 38,130$). The largest three races (Chicago, Disney, and Philadelphia) constituted 64.3% of the sample ($n = 59,140$), and each of the remaining 11 races comprised 1.2%–5.2% of the total participants.

To address racing experience, we obtained information from athlinks.com, a Web site that seeks to aggregate finishers' data from all races. Although some races included information as far back as the early 1980s, information was more comprehensive for races occurring since the early 2000s. We searched for each finisher's name and recorded

TABLE 1. Listing of marathon participants and summary data on percentage change in pace from the first half to the second half by sex.

| Marathon | Total Sample | | | | Women | | | | Men | | | | |
| | Participants | | Percentage Change in Pace (%) | | Participants | | Percentage Change in Pace (%) | | Participants | | Percentage Change in Pace (%) | | |
	Count	Pct.[a]	Mean	SD	Count	Pct.[b]	Mean	SD	Count	Pct.[b]	Mean	SD	P Value[c]
Air Force	3199	3.5	19.2	14.9	1042	32.6	16.9	12.1	2157	67.4	20.3	16.0	<0.0001
Atlanta	1109	1.2	13.8	12.1	422	38.1	11.5	9.6	687	62.0	15.2	13.2	0.0006
Austin	4792	5.2	15.2	13.0	1941	40.5	12.1	10.2	2851	59.5	17.3	14.2	0.0003
Baltimore	3188	3.5	17.7	15.1	1189	37.3	14.4	12.4	1999	62.7	19.7	16.2	<0.0001
Chicago	35,571	38.7	16.0	13.1	15,412	43.3	13.5	10.9	20,159	56.7	17.9	14.2	<0.0001
Cleveland	2598	2.8	10.3	11.0	994	38.3	9.6	10.0	1604	61.7	10.7	11.5	0.0317
Dallas	4473	4.9	10.5	11.4	1702	38.1	8.6	9.4	2771	62.0	11.6	12.3	<0.0001
Disney	13,431	14.6	9.4	11.7	6225	46.4	8.1	10.1	7206	53.7	10.5	12.9	<0.0001
Georgia	2201	2.4	13.7	12.0	788	35.8	10.9	9.1	1413	64.2	15.2	13.1	<0.0001
Grand Rapids	1581	1.7	11.3	13.5	697	44.1	9.5	10.1	884	55.9	12.7	15.6	0.0011
Miami	3498	3.8	12.3	12.5	1245	35.6	10.6	10.7	2253	64.4	13.2	13.3	<0.0001
Philadelphia	10,138	11.0	13.1	12.4	4209	41.5	11.1	10.6	5929	58.5	14.6	13.3	<0.0001
Pittsburgh	4255	4.6	10.8	11.0	1624	38.2	9.0	9.0	2631	61.8	11.9	12.0	<0.0001
St. Louis	1895	2.1	21.6	13.2	640	33.8	18.6	11.8	1255	66.2	23.1	13.6	<0.0001
Total	91,929		14.0	13.0	38,130	41.5	11.7	10.9	53,799	58.5	15.6	14.2	

[a]Percentage of participants in the total sample from the individual race.
[b]Percentage of women and men participants within race.
[c]P value from *post hoc* comparison of percentage change between sexes for each marathon.

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their total number of races, total number of marathons, personal bests for the 5 km and marathon, and earliest year with a recorded race.

Searches for some finishers' names yielded race data from more than one individual (e.g., several people named Jane Jones). In some cases, we were able to determine which races were completed by the marathon finisher of interest because of unique identifiers (e.g., age, hometown). In addition, some runners "claimed" a series of races that they had finished, and these performances thus became identified with a unique member profile. In cases with ambiguities and/or no member profile, we excluded the marathoner of interest. Obtaining experience and ability data in this manner was highly time consuming, so we only investigated a sample of finishers. In particular, we generated a randomized list of approximately 6000 marathoners from the full sample of 91,929 performances; we were able to obtain experience data for 2929 of these.

Three research assistants participated in the acquisition of the experience data, and we investigated the reliability of their work by assigning two of them to independently code 210 marathon finishers who had been previously assigned to other coders. Intercoder reliability for identifying finishers was modest (Cohen $\kappa = 0.51$); in 85 cases, both coders identified the marathon finisher in athlinks.com; in 75 cases, neither identified the finisher; and in 52 cases, one coder but not the other identified the finisher. In cases where both coders identified the finisher, their agreement was good, as follows: total previous races, $r (83) = 0.97$, $P < 0.0001$; previous marathons, $r (83) = 0.97$, $P < 0.0001$; fastest previous marathon, $r (83) = 0.96$, $P < 0.0001$; fastest 5 km, $r (40) = 0.99$, $P < 0.0001$; and earliest year with a recorded race, $r (83) = 0.91$, $P < 0.0001$.

Statistical analysis. The overarching goal of the analysis was to test for sex differences in patterns of pace maintenance over the marathon while adjusting for men's generally faster performances. Furthermore, we sought to control for the potential confounding effects of age and running ability through stratification. Total finishing time, first half time, and second half time were determined from chip times (i.e., when each individual crossed the starting line). The finishing times for men were categorized into <3 h 00 min up to 5 h or more in 30-min increments. Women's categories were shifted up by 12% to account for the sex difference in $\dot{V}O_{2max}$. For example, the <3 h 00 min boundary for men would equate to a 3 h 22 min boundary for women. For analyses using pacing as a continuous variable, the chip times of women were divided by 1.12 to introduce the 12% adjustment.

Pace maintenance was operationalized by calculating the percentage change in the pace observed in the second half of the marathon relative to the first half pace (% change = (second half time − first half time)/first half time). This percentage change was used as a continuous variable and for two categorizations. For the first categorization, percentage changes less than 10% were considered "maintaining the pace." For example, a runner who completed the first half of the marathon in 2 h 0 min and completed the second half in 2 h 11 min or faster maintained the pace; those who took 2 h 12 min or slower failed to maintain the pace. For the second categorization, percentage changes greater than 30% were considered as "marked slowing." This classification was created to represent a transition from running in the first half to considerable walking during the second half of the race. For example, a runner who completed the first half of the marathon in 2 h 0 min and the second half in 2 h 36 min or slower exhibited marked slowing. Mantel–Haenszel techniques for stratified data were used to summarize the odds for maintaining, or not, the pace during the race when controlled for age, first half pace, and race. In instances where the odds ratio (OR) was not defined because of a zero cell, the empirical logit was used for computation. This estimator for the OR added 0.5 to each of the cell before the calculation of the stratum-specific OR and the overall pooled estimate.
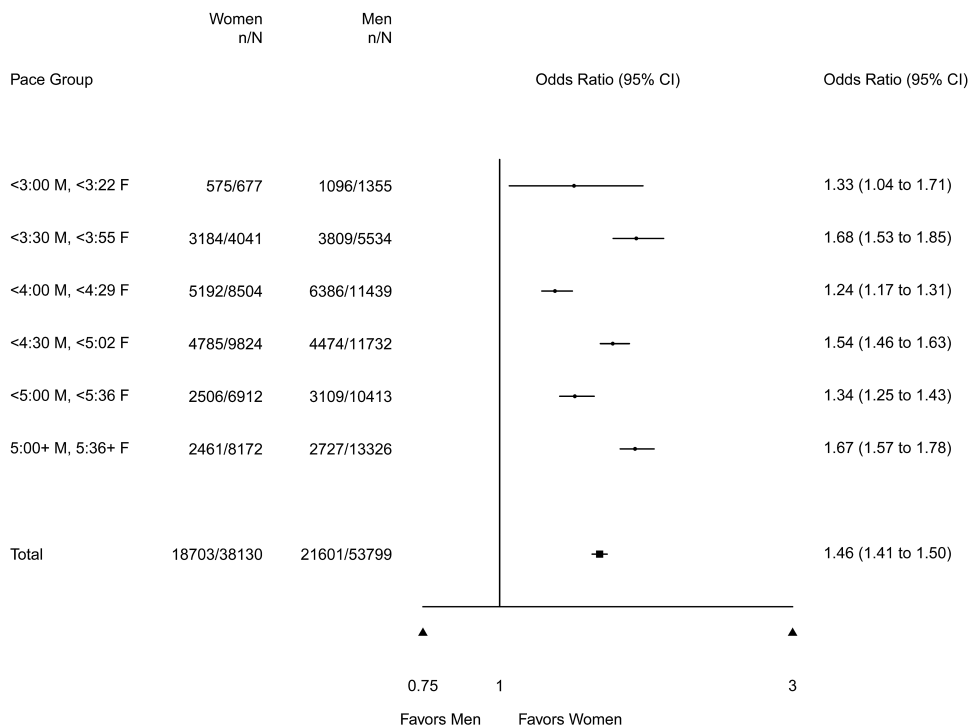
These categorizations enabled ease of interpretation and graphical display. To ensure statistical efficacy, regression analyses were also used to test for coincidence of regression lines for men versus women using the continuous percentage change in pace by finishing time. In addition, multiple linear regression techniques were used to explore the relation of experience variables with the percentage change in pace.

TABLE 2. Percentage slowing by sex and finishing time group. Finishing time groups for women have been adjusted by 12% to account for $\dot{V}O_{2max}$ differences.

Sex	Finishing Time	*n*	Mean (%)	SD (%)	Maintained the Pace (<10% Slowing)		Marked Slowing (≥30% Slowing)	
					n	Pct.	*n*	Pct.
Women	<3 h 22 min	677	5.0	6.0	575	84.9	2	0.3
	<3 h 55 min	4041	5.7	6.5	3184	78.8	13	0.3
	<4 h 29 min	8504	8.7	8.4	5192	61.1	125	1.5
	<5 h 02 min	9824	11.3	10.1	4785	48.7	436	4.4
	<5 h 36 min	6912	14.6	11.5	2506	36.3	585	8.5
	5 h 36 min or more	8172	16.5	12.5	2461	30.1	930	11.4
Men	<3 h 00 min	1355	5.6	6.6	1096	80.9	12	0.9
	<3 h 30 min	5534	7.6	8.1	3809	68.8	85	1.5
	<4 h 00 min	11,439	10.3	10.4	6386	55.8	529	4.6
	<4 h 30 min	11,732	15.0	12.4	4474	38.1	1283	10.9
	<5 h 00 min	10,413	18.6	14.3	3109	29.9	2021	19.4
	5 h 00 min or more	13,326	22.7	16.5	2727	20.5	3586	26.9

Finishing time groups are listed as non–mutually exclusive categories for brevity in presentation. For example, '<3 h 55 min' corresponds to the stratum of finishers having finishing times of 3 h 22 min or greater but less than 3 h 55 min.

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A Maintaining the Pace

Pace Group	Women n/N	Men n/N	Odds Ratio (95% CI)	Odds Ratio (95% CI)
<3:00 M, <3:22 F	575/677	1096/1355		1.33 (1.04 to 1.71)
<3:30 M, <3:55 F	3184/4041	3809/5534		1.68 (1.53 to 1.85)
<4:00 M, <4:29 F	5192/8504	6386/11439		1.24 (1.17 to 1.31)
<4:30 M, <5:02 F	4785/9824	4474/11732		1.54 (1.46 to 1.63)
<5:00 M, <5:36 F	2506/6912	3109/10413		1.34 (1.25 to 1.43)
5:00+ M, 5:36+ F	2461/8172	2727/13326		1.67 (1.57 to 1.78)
Total	18703/38130	21601/53799		1.46 (1.41 to 1.50)

0.75   1   3

Favors Men   Favors Women

B Marked Slowing

Pace Group	Women n/N	Men n/N	Odds Ratio (95% CI)	Odds Ratio (95% CI)
<3:00 M, <3:22 F	2/677	12/1355		0.33 (0.07 to 1.49)
<3:30 M, <3:55 F	13/4041	85/5534		0.21 (0.12 to 0.37)
<4:00 M, <4:29 F	125/8504	529/11439		0.31 (0.25 to 0.37)
<4:30 M, <5:02 F	436/9824	1283/11732		0.38 (0.34 to 0.42)
<5:00 M, <5:36 F	585/6912	2021/10413		0.38 (0.35 to 0.42)
5:00+ M, 5:36+ F	930/8172	3586/13326		0.35 (0.32 to 0.38)
Total	2091/38130	7516/53799		0.36 (0.34 to 0.38)

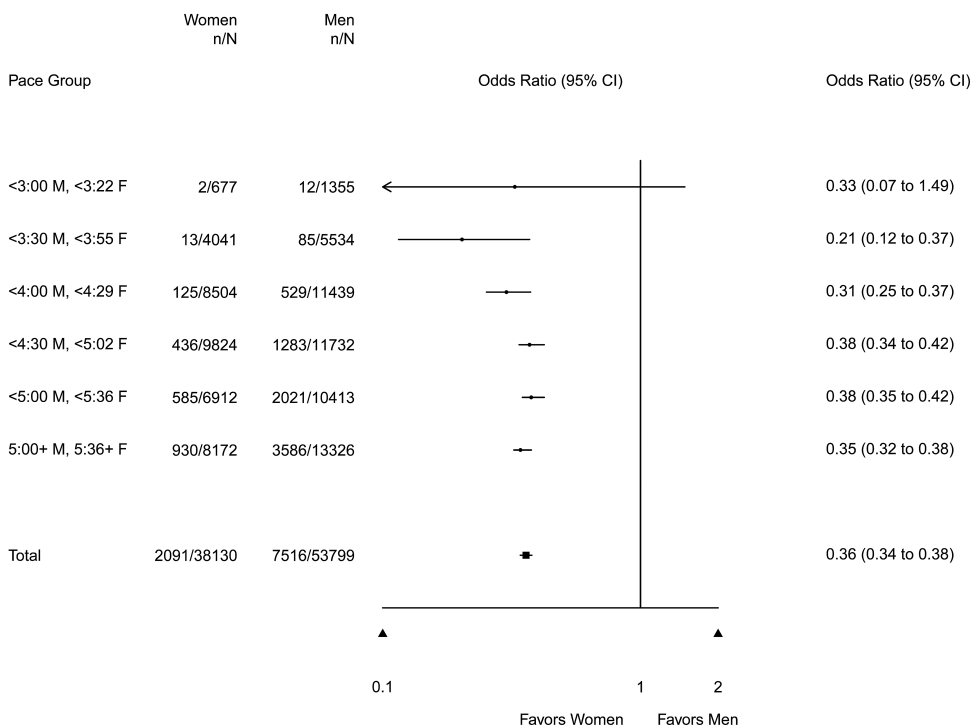0.1   1   2

Favors Women   Favors Men

FIGURE 1—OR of maintaining pace and marked slowing. Forest plot for the odds of maintaining the pace (<10% change in pace) (A) and marked slowing (≥30% change in pace) (B) for women relative to men. The *error bars* are 95% CI. The common estimate is the pooled OR as estimated by the Mantel–Haenszel estimator. "*Favors women*" indicates that women were less likely to slow than men. Conversely, "*favors men*" means that men were less likely to slow than women.

All statistical analyses were conducted using the SAS system version 9.3 (Cary, NC). Two-sided *P* values less than 0.05 were taken as statistically significant.

RESULTS

A total of 91,929 runners (41.5% women) were included in this analysis. The mean ± SD ages for men and women were 38.9 ± 10.8 and 35.5 ± 9.7 yr. The mean finishing times for men and women were 4 h 28 min ± 53 min and 4 h 54 min ± 52 min, a difference of 10%. The mean ± SD changes in pace were 15.6% ± 14.2% and 11.7% ± 10.9% for men and women, respectively (*P* < 0.0001). Although there was variability across marathons, women consistently showed less change in pace (*P* < 0.05 for all 14 marathons) (Table 1).

Pacing and finishing time. Table 2 reports the distribution of percentage change in pace (duration of first half of the marathon relative to the second half) by finishing time group separately for men and women. The finishing time groups for women have been adjusted by 12%, so they are comparable with the performances of men. The percentage change in pace varied across finishing time group for each sex (*P* < 0.0001 for both sexes). Table 2 shows that slower groups had lower percentages of participants who maintained the pace (<10% slowing) and more participants (%) who exhibited marked slowing (≥30% slowing). This pattern of greater slowing with greater finishing times was more pronounced in men than in women (see following section).

We calculated the common (pooled) OR for maintaining the pace (Fig. 1A) and marked slowing (Fig. 1B) for women relative to men across the finishing time groups. Overall, women were 1.46 times (95% confidence interval (CI), 1.41–1.50; *P* < 0.0001) more likely to maintain the pace (<10% slowing) compared with men. There were, however, differences among the finishing time groups (*P* < 0.0001, indicated by a Breslow–Day test for homogeneity). The largest sex differences occurred in the subelite category (3:00–3:30 for men and 3:22–3:55 for women; OR, 1.68; 95% CI, 1.53–1.85) and those with the slowest finishing times (5:00+ for men and 5:36+ for women; OR, 1.67; 95% CI, 1.57–1.78).

Overall, 5% of women and 14% of men experienced marked slowing (≥30% slowing), which resulted in women having 64% lower odds for marked slowing than men (OR, 0.36; 95% CI, 0.34–0.38) (Table 2 and Fig. 1B). This pattern of women showing less odds of marked slowing did not differ significantly across finishing time groups (Breslow–Day test, *P* = 0.11). However, there were only 14 participants (12 women and two men) in the elite group (<3:00 men; 3:22 women), so that the precision of estimated OR was poor (wide CI).

Pacing and age. Figures 2 and 3 display the OR of maintaining the pace and marked slowing for women relative to men, with stratification for finishing time group and age group. The overall (pooled) estimate of the common OR for maintaining the pace with adjustment for finishing time and
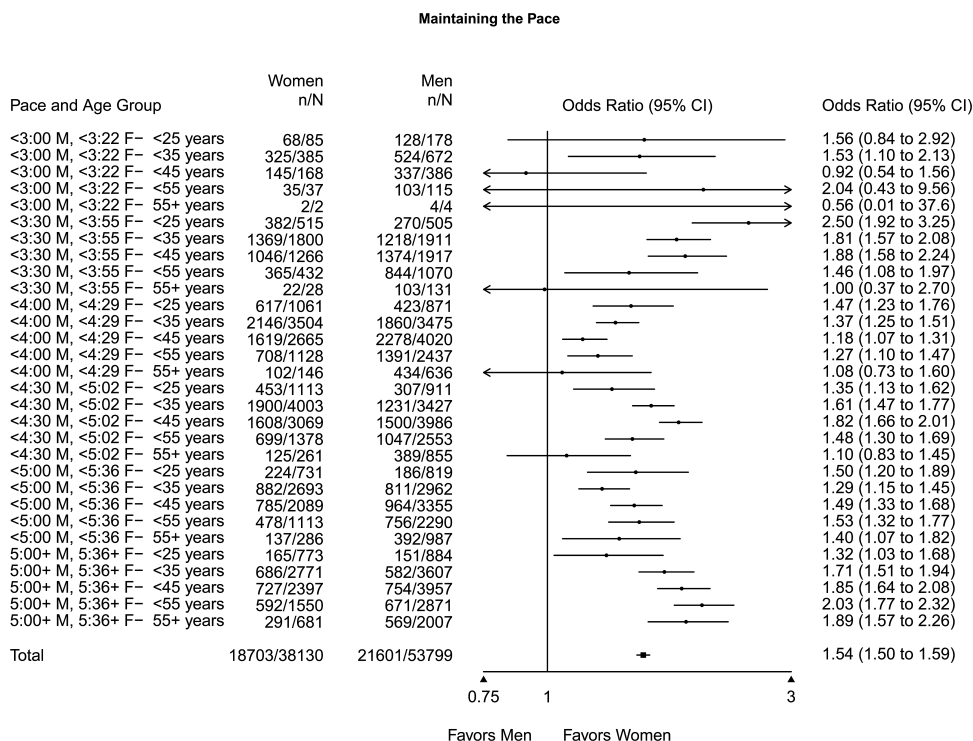
Maintaining the Pace

Pace and Age Group		Women n/N	Men n/N	Odds Ratio (95% CI)	Odds Ratio (95% CI)
<3:00 M, <3:22 F−	<25 years	68/85	128/178		1.56 (0.84 to 2.92)
<3:00 M, <3:22 F−	<35 years	325/385	524/672		1.53 (1.10 to 2.13)
<3:00 M, <3:22 F−	<45 years	145/168	337/386		0.92 (0.54 to 1.56)
<3:00 M, <3:22 F−	<55 years	35/37	103/115		2.04 (0.43 to 9.56)
<3:00 M, <3:22 F−	55+ years	2/2	4/4		0.56 (0.01 to 37.6)
<3:30 M, <3:55 F−	<25 years	382/515	270/505		2.50 (1.92 to 3.25)
<3:30 M, <3:55 F−	<35 years	1369/1800	1218/1911		1.81 (1.57 to 2.08)
<3:30 M, <3:55 F−	<45 years	1046/1266	1374/1917		1.88 (1.58 to 2.24)
<3:30 M, <3:55 F−	<55 years	365/432	844/1070		1.46 (1.08 to 1.97)
<3:30 M, <3:55 F−	55+ years	22/28	103/131		1.00 (0.37 to 2.70)
<4:00 M, <4:29 F−	<25 years	617/1061	423/871		1.47 (1.23 to 1.76)
<4:00 M, <4:29 F−	<35 years	2146/3504	1860/3475		1.37 (1.25 to 1.51)
<4:00 M, <4:29 F−	<45 years	1619/2665	2278/4020		1.18 (1.07 to 1.31)
<4:00 M, <4:29 F−	<55 years	708/1128	1391/2437		1.27 (1.10 to 1.47)
<4:00 M, <4:29 F−	55+ years	102/146	434/636		1.08 (0.73 to 1.60)
<4:30 M, <5:02 F−	<25 years	453/1113	307/911		1.35 (1.13 to 1.62)
<4:30 M, <5:02 F−	<35 years	1900/4003	1231/3427		1.61 (1.47 to 1.77)
<4:30 M, <5:02 F−	<45 years	1608/3069	1500/3986		1.82 (1.66 to 2.01)
<4:30 M, <5:02 F−	<55 years	699/1378	1047/2553		1.48 (1.30 to 1.69)
<4:30 M, <5:02 F−	55+ years	125/261	389/855		1.10 (0.83 to 1.45)
<5:00 M, <5:36 F−	<25 years	224/731	186/819		1.50 (1.20 to 1.89)
<5:00 M, <5:36 F−	<35 years	882/2693	811/2962		1.29 (1.15 to 1.45)
<5:00 M, <5:36 F−	<45 years	785/2089	964/3355		1.49 (1.33 to 1.68)
<5:00 M, <5:36 F−	<55 years	478/1113	756/2290		1.53 (1.32 to 1.77)
<5:00 M, <5:36 F−	55+ years	137/286	392/987		1.40 (1.07 to 1.82)
5:00+ M, 5:36+ F−	<25 years	165/773	151/884		1.32 (1.03 to 1.68)
5:00+ M, 5:36+ F−	<35 years	686/2771	582/3607		1.71 (1.51 to 1.94)
5:00+ M, 5:36+ F−	<45 years	727/2397	754/3957		1.85 (1.64 to 2.08)
5:00+ M, 5:36+ F−	<55 years	592/1550	671/2871		2.03 (1.77 to 2.32)
5:00+ M, 5:36+ F−	55+ years	291/681	569/2007		1.89 (1.57 to 2.26)
Total		18703/38130	21601/53799		1.54 (1.50 to 1.59)

0.75   1   3

Favors Men   Favors Women

FIGURE 2—OR of maintaining pace. Forest plot for the odds of maintaining the pace (<10% change in pace) for women relative to men with stratification for finishing time group and age group. The *error bars* are 95% CI. The common estimate is the pooled OR as estimated by the Mantel–Haenszel estimator. The empirical logit estimator for the OR was used when at least one sex category had no (or all) event (e.g., all men and women in the <3-h marathon finishing time group).
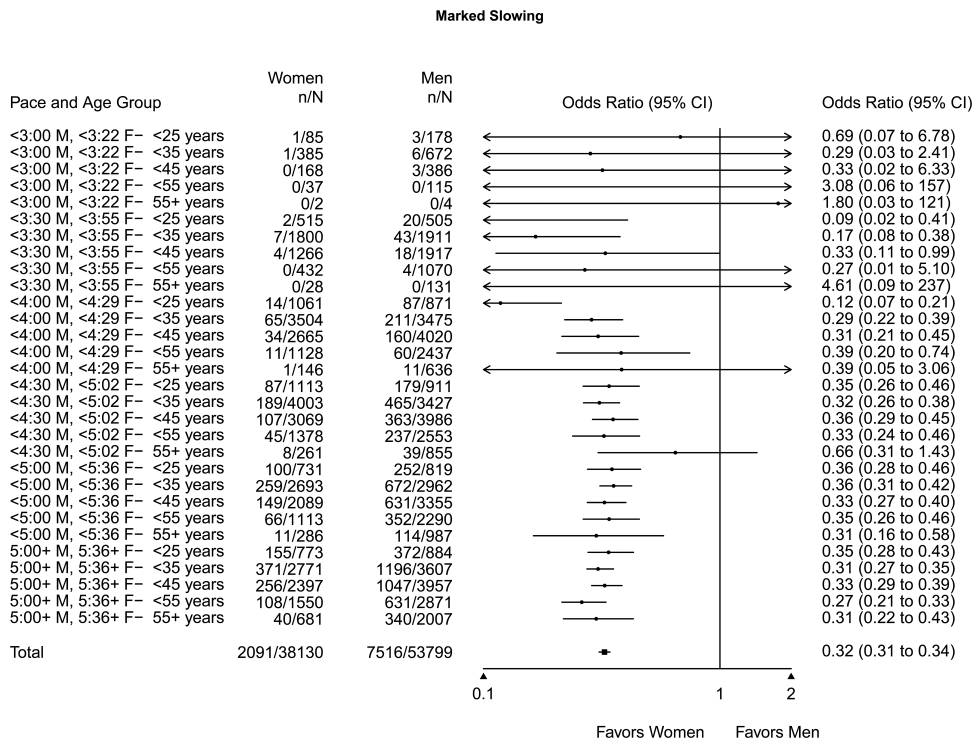
FIGURE 3—OR of marked slowing. Forest plot for the odds of marked slowing (≥30% change in pace) for women relative to men with stratification for finishing time group and age group. The *error bars* are 95% CI. The common estimate is the pooled OR as estimated by the Mantel–Haenszel estimator. The empirical logit estimator for the OR was used when at least one sex category had no (or all) event (e.g., all men and women in the <3-h marathon finishing time group).

age was 1.54 (95% CI, 1.50–1.59; $P < 0.001$) for women relative to men, although there was significant variation across groups (Breslow–Day test, $P < 0.001$) (Fig. 2). For marked slowing, the common OR with adjustment for finishing time and age was 0.32 (95% CI, 0.31–0.34; $P < 0.001$) for women relative to men. Similar to the results presented in Figure 1B, patterns were similar across finishing time and age groups (Breslow–Day test, $P = 0.19$) (Fig. 3).

Change in pace as a continuous measure. To assess the sensitivity of categorizing finishing time and percentage slowing, we conducted regression analyses. Men and women slowed differentially ($F_{2,91925} = 993$, $P < 0.0001$), so that the sex difference widened among slower runners (adjusted for women relative to men by 12%). For instance, percentage slowing for a 3 h 00 min male finisher and 3 h 26 min female finisher (compared because of the 12% adjustment for finishing time) were 6.9% and 5.5%, respectively (25% difference). However, for a 5 h 00 min male finisher and a 5 h 36 min female finisher (12% adjusted), slowing widened to 18.8% and 14.5%, respectively (30% difference). This regression model explained 20% ($R^2 = 0.197$) of the variation in percentage change in pace, but the relations were not strictly linear.

To examine the nonlinear relation more fully, Figure 4A illustrates a locally weighted (LOESS smoother) plot relating finishing times with percentage change in pace for the entire sample. A scatter plot consisting of a random sample of 5000 finishers has been superimposed onto the figure

to add context to these regression fits. Percentage slowing increases more rapidly in men than in women as finishing time increases.

Sensitivity analysis for the 12% adjustment. We next investigated whether our results were sensitive to the 12% adjustment we made to women's performances. Figure 4B displays locally weighted plots relating finishing times to change in pace for the entire sample using no adjustment, 10% adjustment, and 16% adjustment. No adjustment produced a larger estimate of the sex difference in pacing than that when using adjustment (10% or 16%). Furthermore, the sex difference in pacing was smaller with the 16% adjustment than with the 12% adjustment used in our earlier analyses (Fig. 4A). Nonetheless, even with 16% adjustment, the sex difference in pacing remained apparent in all analyses as noncoincident regression lines (i.e., regression lines of women generally indicating less slowing for any given finishing time).

Race experience. Finally, we explored the effect of experience on pacing in a subgroup of 2929 runners. These runners had a mean finishing time of 4 h 36 min and included 42.8% female participants. The overall mean ± SD percentage change in pace was 15.0% ± 13.5%. As with the entire sample, men's percentage change in pace was greater than the women's (16.8% vs 12.5%; $P < 0.0001$). Similar to the entire sample, 12.4% of the racers showed marked slowing, with men showing higher frequency than women (16.7% vs 6.6% respectively, $P < 0.0001$).
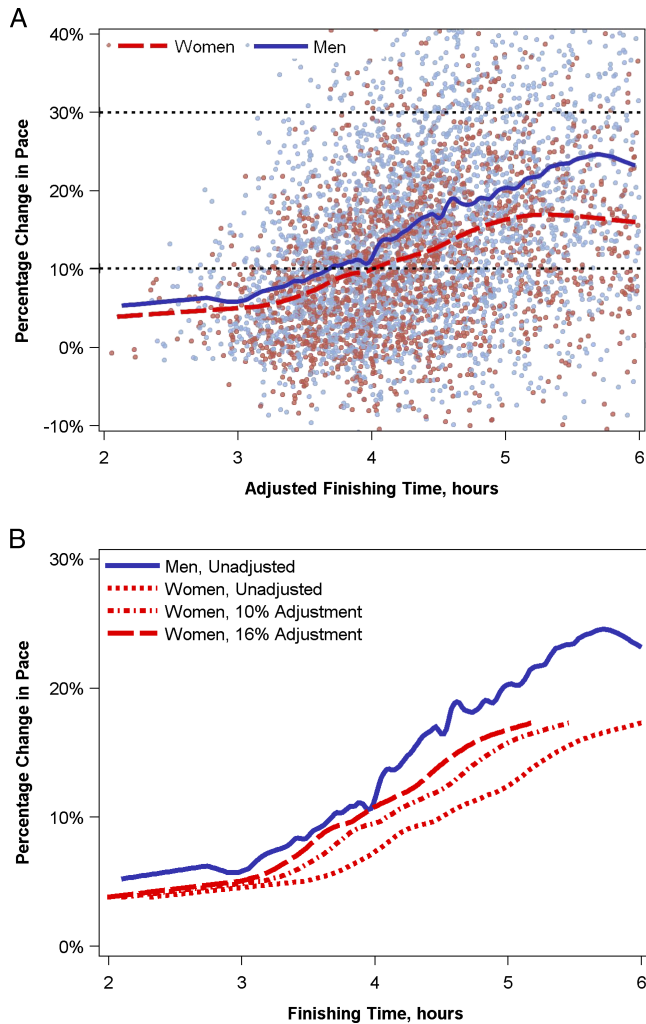
A.

B.

FIGURE 4—Percentage change in pace as a function of finishing time for men and women. A. LOESS-smoothed curves modeling the relation of percentage change in pace as a function of finishing times and for men and women who finished under 6 h ($n = 84,277$). The points plotted are a random sample of 5000 finishers to provide context to the LOESS-fitted lines. Women's finishing times have been divided by 1.12 to account for $\dot{V}O_{2max}$ differences. B. LOESS-smoothed curves modeling the relation of percentage change in pace as a function of finishing times under 6 h ($n = 84,277$) that are unadjusted and adjusted for physiological sex differences. "*Women, 10% adjustment*" indicates that women's finishing times were divided by 1.10; "*Women, 16% adjustment*" indicates that women's finishing times were divided by 1.16.

The next step was assessing which experience variables were significantly related to uneven pacing. We found greater slowing among those individuals with their earliest recorded race after 2008 (≤3 yr of experience) ($\rho = 0.08$, $P < 0.001$), those with fewer previous marathons ($\rho = -0.08$, $P < 0.001$), and those with fewer total races at all distances ($\rho = -0.07$, $P < 0.001$). There was also greater pace slowing among those whose fastest previous marathons were slower ($\rho = 0.19$, $P < 0.001$, in 1856 participants that ran more than one marathon).

Consistent with the findings with the entire data set, the relation of the 12% adjusted finish time and percentage

slowing differed between men and women (test for coincidence, $F_{2,2925} = 38.6$; $P < 0.001$). This model explained 20% of the variation in changes in pacing ($R^2 = 0.197$). With the addition of participant age and the experience variables of total number of previous marathons and recent introduction to marathons (≤3 yr of experience), r^2 increased to 20.8% ($n = 2910$, $R^2 = 0.208$). There was no evidence that the experience variables affected pacing differently in men and women ($F_{2,2901} = 2.06$, $P = 0.13$). In a final model, consisting of the 12% adjusted finishing time, age, total marathons run, recent introduction to the marathon, and sex (the main effects of sex and its interaction with finishing time), the coefficients of partial determinations were as follows: 17.7%, 0.1%, <0.1%, <0.1%, and 2.9%, respectively. Thus, finishing time and the differences between men and women explained the largest percentages of the variation in the change in pace. The estimated percentage point differences in pace change, men relative to women, for relative finish times of 2 h 30 min (i.e., female finish time of 2 h 48 min), 3 h 00 min, and 5 h 00 min were 1.6 ($P = 0.15$), 2.2 ($P = 0.001$), and 4.7 ($P < 0.001$) percentage points after adjusting for these experience variables.

DISCUSSION

This study shows that the sex difference in marathon pacing among nonelite runners is robust in several respects. First, the sex difference was significant in all 14 marathons in our sample. These marathons differed considerably in their size and extent of slowing (Table 1), indicating that the sex difference occurs generally. Second, we showed that, although age (i.e., being an older runner) and faster performances are associated with more even pacing (26), the sex difference generally persists across ages and abilities. There was evidence, however, for an interaction, with a less pronounced sex difference among faster runners. Third, we demonstrated that adjusting women's performances by 12%—to address men's greater $\dot{V}O_{2max}$—does not eliminate the sex difference in pacing. Fourth, we found that, although inexperience is associated with greater pace slowing, controlling for experience does not eliminate the sex difference. Finally, our study is notable in its exploration of pace slowing as both a continuous and a categorical variable. Thus, rather than merely stating that men slowed more than women on average, we showed that, after controlling for age and ability and making the 12% adjustment, women had approximately one-third the odds as men to experience marked slowing (running the second half of the race more than 30% slower than the first half).

Besides demonstrating the robustness of the sex difference in pacing, our study yielded other notable results. One finding is that, making a 12% adjustment to women's performances did affect the magnitude of the sex difference in pacing. In particular, the sex difference was larger without an adjustment, indicating that previous studies that did not make an adjustment may have overestimated the sex difference in pacing (26,35). Nonetheless, even with the 12%

adjustment, evidence for the sex difference in pacing remained reliable. We also showed that although the estimated sex difference in pacing is generally insensitive to the exact adjustment used (between 10% and 16%), the sex difference in pacing decreases as the adjustment increases.

Our study also provided the first results directly bearing on the hypothesis that experience is related to pacing in the marathon (26). We showed that four experience variables were significantly associated with pacing, namely, years of experience, previous marathons, previous races at all distances, and fastest previous marathon. Thus, more experienced runners paced more evenly and inexperience was associated with greater pace slowing. Moreover, at least two of the experience variables (total marathon run and recent introduction to the marathon) explained variation in pacing independent of the effects of age, finishing time, and sex. The amount of variation explained by the experience variables, however, was modest (>0.1% for each) compared with sex (2.9%) and finishing time (17.7%). Consequently, controlling for experience does not eliminate the sex difference.

What causes the sex difference in pacing? Various physiological factors might contribute to the sex difference in marathon pacing, although we did not measure these. For example, men are more susceptible to muscle glycogen depletion, which can contribute to greater fatigability and "hitting the wall" or dramatic marathon slowing (4,9,30,33). Men may be more susceptible to slowing because, during endurance exercise, women generally have a lower RER, indicating that they use proportionately more fat and less CHO at a given intensity of exercise (7,25,34,36). In general, women possess larger proportional areas of Type I muscle fibers, which are more resistant to fatigue especially for long-duration exercise (19). Supporting this hypothesis are studies finding that men are more likely than women to report dramatic slowing or hitting the wall (4,33).

Another possibility is that men might be more susceptible to hyperthermia (35), which is believed to be another frequent contributor to marathon slowing (16,27). Supporting this is the finding that the sex difference in marathon pacing in nonelites was larger in the 2007 Chicago marathon, which was hot (27°C), than that in the 2009 Chicago marathon, which was cool (3°C) (35). Challenging this hypothesis, however, are studies indicating that men typically enjoy advantages in thermoregulation (14).

Decision making could also contribute to the sex difference in marathon pacing. Specifically, if men are more likely to adopt a "risky" or competitive pace relative to their ability, this could increase their likelihood of slowing later. This is because a fast pace has numerous physiological consequences, including increasing the risk of hyperthermia and glycogen depletion (3,9,13,37). Evidence for a sex difference in pacing decisions comes from a study showing that marathon performances among nonelites tend to cluster at round numbers (e.g., just under 4 h) because of some runners speeding up in the final 2.2 km of the race; this pattern was substantially more pronounced among men than among women (2). There is also

evidence that male distance runners are more likely to adopt a competitive rather than a recreational orientation towards the sport, as follows: 1) more male than female runners report that competition motivates them to run (6,22,29), 2) roughly three times as many men as women run fast relative to sex-specific world-class standards, and this may reflect that that more men engage in the training necessary for faster performances (11), and 3) when men and women have the option of entering a single-sex competitive road race or a single-sex noncompetitive road race, men are more likely than women to select the competitive race (15). In addition, there is much evidence for sex differences in risk taking in other contexts, including health, recreation, and finance (5,10,18).

Does the sex difference narrow among faster runners? Another interesting question is whether the sex difference in pacing is less among faster runners. Addressing this question is important because it could provide clues about the cause(s) of the sex difference. Within financial domains, for example, studies report that the sex difference in risk taking substantially weakens or disappears when financial knowledge is controlled (12,17,23).

In the present study, despite the large overall sample size, there were very little data on genuinely elite or even near-elite runners. Moreover, faster runners, both men and women, generally maintain even paces (Table 2 and Fig. 4A). Notwithstanding these considerations, we did have some relevant results, although they provide an ambiguous answer to the question of whether the sex difference in pacing narrows among faster runners. On the one hand, the sex difference in pacing occurred among all finishing time groups (Table 2 and Fig. 1), and among runners in our two fastest groups (men running faster than 3:00 or 3:30; women running faster than 3:22 or 3:55), the magnitude of the sex difference based on categorical variables (i.e., OR) was similar to the sex difference across all finishing time groups (Table 2 and Fig. 1). On the other hand, when using continuous measures, the significant interaction of sex with adjusted finishing time indicates that the sex effect was significantly less pronounced in faster runners (Fig. 4A). Specifically, we estimated that among faster runners (3 h 00 min male finisher and corresponding 3 h 26 min female finisher), men slowed, on average, 25% more than women, whereas among slower runners (5 h 00 min male finisher and corresponding 5 h 36 min female finisher), men slowed, on average, 30% more than women.

We note that there have been several studies on pacing among elite men and women in other endurance sports. These typically indicate no pacing differences (28) or else subtle differences that are difficult to interpret because of sex-specific aspects of the competition, such as the depth of competitors (37).

Are women more effective pacers? There is consensus that even (or nearly even) pacing is best for optimizing performance in races that take several hours to complete, such as marathons (1). Furthermore, dramatic pace slowing in a marathon is associated with considerable discomfort (4,33). Our results therefore imply that women are generally more effective than men in their marathon pacing. Nonetheless, this

conclusion should be considered provisional because an evenly paced race does not automatically indicate a well-paced one. This is because an individual may be overly conservative given their training and ability. Similarly, although dramatic slowing in a race almost certainly indicates a poor outcome for that race, a risky initial pace may be desirable in a broader context. For instance, if a runner's goal is to achieve at least one exceptional performance during the year (e.g., setting a personal record, winning their age group), he/she may have the best chance of achieving it if he/she often begin his/her races with a fast risky pace. Thus, a definitive answer to the question of whether particular groups or individuals are better pacers requires comprehensive assessment of goals.

Insights from nonelites. Much has been gained from studying the pacing of elite and subelite endurance athletes (1), and investigating the pacing of nonelite or recreational athletes may provide further insights. For example, besides sex difference, our study confirms that older runners and runners with faster initial pace tend to pace more evenly (26) and, to our knowledge, none of these effects were predicted by studies on elite pacing. Moreover, the variation in pacing among nonelites shown in our study (Fig. 4A) seems far greater than that among elites (13). This is probably due to the tremendous diversity of nonelites' goals, training, and abilities (2,11). We suggest that future studies of pacing in nonelites assess these factors and others (e.g., coaching, fluid and CHO ingestion, use of pace groups, and targeted pace) to illuminate the interactions among physiological and psychological factors in pacing. This research would seem of interest to many scientists and perhaps also to the public. For example, although marathon training handbooks, magazines, and Web sites generally contain sound advice, their discussions of pacing might be improved considerably as the factors related to uneven pacing are identified.

Limitations. The current study is not without limitations. First, we evaluated pacing only by assessing first and second half split times, so we were unable to model when the slowing typically began. Other studies indicate that slowing becomes pronounced in the final 10–15 km of the marathon (4,13,26). Second, we did not account for pacing variation associated with race courses or weather conditions and this variation may be substantial (13,35). Third, although we succeeded in identifying experience factors associated with pacing variation, other experience factors that we did not assess may also be important. Similarly, as noted previously, we had no individual data on other relevant factors, including training, CHO ingestion, and targeted pace. Fourth, some runners may have participated in more than one race in our sample. We were unable to "cluster" performances under a given participant, and this could have led to CI values being smaller than they would have been if clustering was modeled explicitly.

CONCLUSIONS

This study demonstrates that the sex difference in pacing among nonelite marathon runners is robust and greater among slower runners. It occurs consistently across marathons, persists across age groups and ability levels, and remains when experience is controlled and when women's performances are adjusted to address men's greater $\dot{V}O_{2max}$. The causes of the sex difference in pacing are presently unknown, but they likely involve the interplay of physiological and psychological factors. Studying this sex difference and related pacing phenomena should yield performance insights for scientists, coaches, and athletes.

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