Marathon performance and pacing in the Doha 2019 women's IAAF World Championships: Extreme heat, sub-optimal pacing and high failure rates

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Abstract

Purpose. The Doha 2019 women's World Championship marathon took place in extreme hot (32ºC), humid conditions (74% relative humidity [RH]) culminating in unprecedented (41%) failure rates. We explored whether extreme heat, or sub-optimal pacing was responsible for diminished performance against a temperate 'control' (London 2017; 19ºC, 59% RH) and whether physical characteristics, (e.g., body surface area, estimated VO_{2max}, habitual heat exposure) explained performance. **Method.** Five-kilometre (km) pace ($km.h^{-1}$) data underwent repeated-measures analyses of hot (Doha, n=40) vs temperate pacing and performance (London, n=78); within and between marathon pacing (finisher quartiles normalised against personal best; n=10 per group), and within hot marathon finishers vs non-finishers (up to 10km; normalised data). Possible predictors (multiple regression) of hot marathon pacing were explored. Tests to 0.05 alpha level, partial eta squared (ηp^2) indicates effect size **Results:** Mean±SD Doha (14.82±0.96$km.h^{-1}$) pace was slower (London 15.74±0.96$km.h^{-1}$; p=0.00; ηp^2=.500). In hot conditions, athletes finishing in positions 1-10 (Group1) started more conservatively (93.7±2.1% of PB) than slower runners (Groups 3 & 4; 96.6±2.8% of PB; $p<0.05$, ηp^2=.303). Groups were not different at 15-km and then slowed immediately (Groups 3&4) or after 20-km (Group 2). Finishers and non-finishers adopted similar pace up to 10-km ($p>0.05$, ηp^2=.003). World ranking predicted (p=0.00; r^2=0.248) average pace in Doha. **Conclusion.** Extreme hot conditions reduced performance. Top 10 athletes adopted a conservative initial pace whereas lower-placing athletes adopted a faster, aggressive start. Pacing alone does not explain high failure rates in non-finishers. Athletes competing in the heat should initially pace conservatively to optimise performance.

Keywords. Marathon running, pacing strategies, IAAF world championship, temperature change.

Introduction

The 2019 World athletics Championships took place in Doha in hot (~32ºC), humid conditions (~74% relative humidity[RH][1]) that were forecast to increase the risk of heat-related illness.[2] IAAF guidelines indicated that these conditions (i.e., >28 ºC WBGT) are classified as "extreme" and carry "black flag" categorisation requiring organisers to consider rescheduling to cooler conditions or be on "high alert" should the event take place.[2] Instead, organisers sought to reduce the risk to athletes by providing evidence-based recommendations to prepare athletes prior to and during competition.[3] These included undertaking a period of heat-acclimation/acclimatisation (e.g., HA[4]), maintaining hydration[5], implementing pre and in-event cooling[6], and providing acute strategies, such as cold water immersion, to treat heat-illness should it occur. Nevertheless, these recommendations did not prevent significant athlete failure rates in some endurance events at the 2019 World Championships.[1]

The women's World Championship marathon took place on the 27th September, 2019 and commenced at midnight to coincide with the nadir in ambient temperature, but not humidity.[2] During the event athletes were offered additional cooling interventions (i.e., soaked sponges) and regular drink stations.[1] Despite these efforts, an unprecedented number of athletes failed to complete the event (41%, 28 of 68 athletes failed) when considered against the previous edition in London 2017 which took place in temperate conditions (15%, 14 of 98 athletes failed). Most athletes in Doha (26) withdrawing before completing 15 km of the 42.2 km race distance. Subsequent evidence suggested that poor uptake of pre-event preparatory advice and in-race mitigation strategies was not accountable for the athlete drop out.[1] Therefore, this unprecedented level of failure requires an alternative explanation.

Exercise pacing is defined as the regulation of energy expenditure to allow an individual to complete a task (e.g., run a marathon) in the fastest time whilst controlling homeostatic disturbance[7] (e.g., exertional heat illness) and could be tailored to optimise performance in exceptionally hot conditions. Pacing is a form of behavioural thermoregulation and, if deployed effectively, could optimise performance and prevent failure.[8, 9] Yet, few athletes, coaches and scientists advocate this approach as viable performance strategy in the heat, presumably because it involves an athlete running more slowly than they can sustain in temperate conditions, risks under-performance if inaccurately applied, and is relatively untried; this might explain why modifying pace was not advocated to aid endurance performance in Doha.[3] Nevertheless, experienced athletes are known to be more effective at deploying changes to exercise pacing than less-experienced ones[10] who may adopt an overly-ambitious, sub-optimal or 'catastrophic' pacing profile particularly when the task environment is unfamiliar.[11] Therefore, an analysis of elite athlete pacing in events where unprecedented drop out is seen may help explain the aetiology of task failure. A conclusion of failed pacing may help tailor future guidance given to athletes to minimise heat-related illness.

Whilst effective exercise pacing may distinguish successful exercise performance in the Doha 2019 women's marathon, it is also possible that those who successfully tolerate such hot conditions do so because of favourable phenotypic characteristics that are maximised by effective training and preparation.[12] For example, individual body dimensions (e.g., body mass, body surface area to mass ratios) are known to influence the magnitude of sudomotor and cardiovascular responses to heat exposure influencing effective avenues for heat exchange with the environment.[13, 14] Yet the unexplained variance in thermoregulatory response is also known to be high (i.e., ~72%; [15]) during exercise in hot, humid conditions, suggesting an interplay between inherent and acquired physiological characteristics. Part of this variance may be accounted for by the extent of HA achieved by athletes in preparation for Doha 2019. HA is likely to partially benefit athletic performance in the heat through expanded blood plasma volume[4], increased sweat rate[4] and reduced deep body temperature for given work rate[12] to improve heat tolerance. However, not all athletes engage with this recommended practice[16] and HA protocols do not entirely explain human performance in hot conditions.[17] It is also possible that habitual heat exposure may prove influential at these extremes, as has been shown in relation to cold climates where latitudinal cline is a predictor of regional cold sensory acclimatisation.[18] Therefore, we also sought to explore whether inherent characteristics influenced performance in these hot-humid conditions.

Accordingly, the present study examined whether marathon pacing and performance was affected by the hot, humid conditions experienced in Doha when compared to the preceding women's World Championship marathon which took place in temperate conditions (i.e., London, 2017); we hypothesized it was (H_1). In explaining sub-optimal performance in those who completed the Doha women's marathon we hypothesized that less successful athletes utilized sub-optimal pacing, such as an overly-ambitious early pace (H_2). We also hypothesized that athletes who failed to finish would exhibit a catastrophic pacing profile characterized by an early aggressive pace that could not be sustained precipitating drop out (H_3). Lastly, we hypothesized that the best-performing athletes in Doha 2019 would possess the most favorable characteristics for heat exchange with the environment (H_4).

Method

Study Design

Ethical approval for the analyses of this publicly available data were granted by Leeds Trinity University Ethics and Integrity Committee (SHSS/2020/19). The study adopted both within and between-participant repeated measures designs to compare athlete pacing and performance within a hot marathon (Doha IAAF World Athletics Championship, 2019), between-groups (determined by finishing position) within the hot marathon, and relative to a temperate marathon 'control' (IAAF World Athletics Championship, London, 2017).

Doha, 2019 Event Characteristics

Average temperature throughout the event confirmed the "black flag" classification[2] (32.0 ± 0.7 ºC; 77.9 ± 2.3% RH (WBGT 29.6 ± 0.3 ºC); wind speed 0.1 ± 0.2 $m.s^{-1}$).[1] The course consisted of six laps of a flat 7.25km circuit at the Doha City Corniche, Qatar. Extra provisions for the athletes to mitigate heat stress included seven drinks stations (1km apart) consisting of three personal drink stations and four general use stations (including wet sponges) placed along the course.[1]

London, 2017 Event Characteristics

Average temperature on the day confirmed a "green flag" classification[2] (19°C; 56% RH (WBGT 15.5 ºC); wind speed 5 $m.s^{-1}$) and commenced at 2 p.m. local time. The course consisted of four laps of a primarily flat 10.55km circuit. Following standardised event protocols, athletes had access to fluids every 5km.[19]

Marathon Data

The study used publicly available secondary data describing marathon pacing and performance at the Doha 2019 and London 2017 IAAF World Athletics Championship.[19, 20] This included a start list, finishing times, positions and split times (5km London, 1km Doha).

Data Synthesis

Pacing and performance data were accessed and extracted for initial analysis in Microsoft Excel (*v*16.48 Microsoft, Redmond, WA, USA). Pacing strategy was analysed across 5km sections (8 split times) and a final 2.195km section. The 1km Doha split time data were averaged across 5km segments to align with the lowest resolution available for the London data. Any missing data points were calculated by extrapolation from adjacent split times.

To examine the potential contribution of inherent characteristics to performance in Doha, athlete data for stature (i.e., height and mass), 5km personal best, nationality and marathon world ranking (at the time of the race) were accessed.[20] Characteristics for environmental heat exchange (i.e., body surface area [BSA], BSA:mass ratio) were calculated by estimating BSA.[21] Estimated maximal oxygen uptake (VO_{2max}) was calculated from 5km personal best.[22] Habitual heat exposure was estimated from latitude measurements of the capital city of the home nation of each athlete.[18] World ranking was used as an index of performance level.

Statistical Analysis

Data are reported as mean ± standard deviation (SD) with 95% Confidence Intervals (CI) where appropriate. All statistical analyses were carried out using SPSS (*v*27, IBM SPSS statistics, Chicago, IL, USA) to an alpha level of 0.05. Obeserved power (β) and effect size (partial eta squared (η_p^2) are reported where appropriate. Data were checked for normality using the Kolmogorov-Smirnov test.

Pacing and performances within and between athletes who completed the Doha (hot marathon; n=40) and London (temperate, n=78) conditions were examined by repeated measures analysis of variance (rmANOVA) among nine (eight 5 km sections and the final 2.195km) distance points and between marathons (pace; $km.h^{-1}$). To establish the different approaches to exercise pacing adopted by the top performing athletes who completed the Doha and London World Championship marathons, comparisons were made among four stratified groups using rmANOVA (pace × group × marathon). These were: Group 1 (finishers 1 to 10), Group 2 (finishers 11 to 20) Group 3 (finishers 21 to 30), and Group 4 (finishers 31 to 40). To establish pace relative to best performance, running pace was normalised against each athletes' personal best (PB) marathon performance correct to the date of each race.[23] To examine if a different pacing strategy was adopted by the finishers (n=40) versus non-finishers of the Doha marathon only (n=28), rmANOVA was conducted up to the distance point (i.e., 10 km) prior to when the majority of non-finishers dropped out from the race (i.e., 15 km; n=2 non-finishers remaining); data were normalised against PB. Assumptions of sphericty for rmANOVA were checked using Mauchley's test and were corrected using the Greenhouse-Geisser adjustment where required. Significant ANOVA main effects were assessed *post-hoc* with pairwise comparisons. Between group *post-hoc* differences were identified using a Scheffe or pairwise comparison test as appropriate.

Predictors of marathon performance in the heat were explored in a total of 20 participants; this analysis was limited by available data. A linear stepwise multiple regression analysis was conducted to establish if the following inherent characteristics were predictors of average normalised hot marathon (against PB) running pace or performance (completion time): height, mass, BSA, BSA:mass ratio, estimated VO_{2max}, latitude and world ranking. Pearson correlation coefficients were also calculated to examine for inter-relationships between the predictors.

Results

Descriptive Data

Seventy athletes, with an average age of 30 ± 5 years from 41 countries, entered the Doha women's World Championship marathon. Forty athletes, with an average PB (hh:mm:ss) of 02:29:44 (± 00:05:18) completed the event (~41% non-completion rate) with a winning time of 02:32:43 (hh:mm:ss) and a time of 03:19:13 for the last placed runner; two runners did not start. Ninety-two athletes, with an average PB for the top 40-runners of 02:27:33 (± 00:05:07) and average age of 30 ± 5 years from 47 countries, entered the London World Championship. Seventy-eight athletes completed the event (~15% non-completion rate) with a winning time of 02:27:11 and a time of 03:05:03 for the last placed runner. Mean ± SD descriptive data for Doha and London marathons are in table 1.

INSERT TABLE ONE HERE

Marathon Pacing and Performance in Hot vs Temperate Conditions (H_1)

The average pacing profile of athletes in both the 2019 Doha and 2017 London marathons were characterised by a positive pacing profile, with mean running speed decreasing progressively from the outset (main effect for pace: $F_{(1.984,230.122)}$= 116.081, p= <0.001 ηp^2= .500, β= 1.00); figure 1. However, the overall running speed was significantly slower in Doha compared to London (main effect for marathon: $F_{(1,116)}$=24.341, p= <0.001, ηp^2= .173, 95% CI= .55 to 1.30 kmh^{-1} slower, β= .998) and the rate at which running pace declined was significantly greater in Doha compared to London (significant pace by marathon interaction effect: $F_{(8,928)}$= 9.635, p= 0.001 ηp^2= .046, β= 1.00). *Post-hoc* analysis revealed that running pace across each 5km section was slower in Doha with the exception of the final 2.195km (p=.068). Both events showed evidence of an end-spurt either maintaining (London) or increasing pace (Doha).

INSERT FIGURE ONE NEAR HERE

Marathon Pacing and Performance in Hot vs Temperate Conditions- Top 40 Finishers (H_2)

Pre-event PBs for the top 40 finishers in the Doha and London marathons were not different (independent samples t-test; t=1.883, p>0.05). Pacing and performance characteristics of groups stratified by finishing position are reported in table 2. This analysis primarily focuses on the approach to pacing relative to individual PB. Finishing position in the stratified groups were associated with a different pacing profile relative to individual PBs (marathon by group interaction: $F_{(3,72)}$= 10.454, p= <0.001 ηp^2= .303, 95% CI= 91.32 to 92.33 %, β= .998). Post-hoc analysis revealed that all finisher groups in Doha differed between each other in their relative pace sustained whereas none differed in London; table 2

When potential effects were considered between marathons and position groups (Marathon by Distance by Group interaction: $F_{(24,576)}$= 4.285, p= <0.001 ηp^2= .151, 95%, β= .997), Group 1 runners in Doha ran at a similar relative pace at 5, 15 and 35km to those in London (p=.330, .329 & .061) and were slower at all other points. Group 2 and 3 runners in Doha were only similar at 5km (p=.061&.142) and were slower thereafter. Group 4 runners were slower in Doha at all points; figure 2. Collectively the extent of differences in pacing strategy for the top 10 athletes was much smaller with a pacing profile distinct from all other finisher groups; figure 2A. Absolute data were slower in Doha at all distance points in all groups (data not shown).

INSERT TABLE TWO AND FIGURE TWO NEAR HERE

Marathon Pacing in the Heat – Finishers vs Non-Finishers (H_3)

Athlete pacing relative to PB (finishers vs non-finishers) are reported in figure 3. Finishers (n=40) and non-finishers (n=26) had similar times at 5km and 10km and both groups had slowed equally by at 10km, (main effect for 5km split time: $F_{(1,64)}$= 70.658,p= <0.001 ηp^2= .525; 95% CI= 1.63 to 2.65 % slower at 10 km distance). Both groups followed the same pacing profile with no difference between groups in overall self-selected pace (no main effect for finishing status: $F_{(1,64)}$= .206, p=.651, ηp^2= .003, 95% CI= -.912 to 1.45 % grouped across 5 and 10 km distance, β= .073).

INSERT FIGURE TWO AND THREE NEAR HERE

Predictors of Marathon Performance in the Heat (H_4)

None of the anthropometric independent variables entered for regression held a predictive relationship with the percentage of PB sustained (pace) or completion time in the Doha marathon. In both cases, only World ranking proved to be predictive (Pace: $F_{(1,19)}$= 5.928, r^2= 0.248, adjusted r^2= 0.206, p=.026; Completion time: $F_{(1,19)}$= 9.102, r^2= 0.336, adjusted r^2= 0.299, p=.007) accounting for 20.6% and 29.9% of the variance, respectively. The unstandardised coefficient, (B=-.007 & B=1.937), indicated that every unit change in world ranking corresponds to <0.10% change in relative pace and 01:56 (mm:ss) change in completion time for a hot marathon. Pearson's correlation indicated estimated VO_{2max} was related to average pace (r=.419, p= .033).

Discussion

Our analyses indicate that average marathon performance was reduced in the hot-humid conditions of Doha compared to the temperate conditions of London, with the average

Doha marathon pacing-profile characterised by a greater drop-off in pace (i.e., a more positive pacing profile; figure 1) over the course of the event; H_1 accepted. However, athletes who performed successfully in Doha (finishing positions 1-10) adopted a more conservative initial exercise pace, which they were able to sustain over the course of the event. Less successful athletes (all other finishing positions) adopted an initial exercise pace that was more ambitious, relative to their personal best, and subsequently unsustainable in the hot-humid conditions (figure 2); H_2 accepted. Lower placing athletes in Doha also produced an end-spurt, suggesting an unspent energetic reserve and sub-optimal pacing. Finally, there was no evidence for differences in the pacing strategy adopted by finishers and non-finishers of the Doha marathon (H_3 rejected; figure 3), whilst the examined physiological characteristics were not predictive of marathon performance in the heat (H_4 rejected).

The finding that marathon running performance was impaired in the hot condition of Doha is consistent with extant literature.[24, 25] Previous research has suggested that at a WBGT of between 20 and 25°C the performance of female marathon runners is reduced by 5.4%.[23] The magnitude of impairment was ~3 times larger in the present study (14.7% slower than athlete PB in Doha) highlighting the debilitative nature of the environment (WBGT ~30°C). Interestingly, this difference was smaller when comparing the winning times between these events (3.8% or 05:32 mm:ss slower in Doha than London) and there is some evidence that faster runners are less affected by hot conditions[25] although the confounding influence of different race tactics could also contribute to this observation. Nevertheless, exercise in the heat is associated with an elevated thermoregulatory burden, including increased cardiovascular strain and pulmonary ventilation, altered muscle metabolism and cerebral function, as well as central fatigue related to effects on the dopaminergic system (see Nybo et al[26]for a review). The integrated effects of these physiological mechanisms were likely responsible for the reductions in marathon running performance in the heat compared to cooler conditions.

On average, the Doha marathon pacing-profile was characterised by a greater drop-off in pace (i.e., a more positive pacing-profile) compared to London (figure 1 & 3). Positive pacing is typical to marathon running in the heat[25] and is at odds with the optimal pacing profile for fast marathon times; the fastest marathons i.e. world record performances are typically run with an even-pace or slight negative-split pacing profile.[27] Interestingly, the average pacing in profile in London also displayed a progressive slowing over the marathon distance, although to a lesser extent than in Doha. Indeed, despite being classed as a green flag WBGT, statistically significant reductions in marathon time have been observed at WBGTs >10°C compared to lower WBGTs[28], indicating that there may have been some modest thermal burden encountered by the runners in London.

Pacing data, stratified by finishing position, indicated that the pacing-profile of the athletes who performed best (i.e. positions 1 to 10) in the hot conditions of Doha was initially more conservative than those finishing in the lower positions (i.e. 11 to 40). Athletes finishing in the highest positions displayed a relatively even-pacing profile, (92.7 ± 2.4 % of PB), with little evidence of end-spurt. This is consistent with the bioenergetic optimum displayed in world record breaking marathons[27], whereas adopting (and maintaining) a reduced initial exercise pace (relative to PB) is compatible with concept of anticipatory regulation in which exercise pace is reduced early in the event, in advance of attaining dangerously high deep-body temperatures.[29] Taken together these data suggest a near 'optimisation' of pacing for the hot-humid conditions by high-finishing athletes. Conversely, lower placing athletes were more ambitious in their initial pace, which precipitated a pronounced progressive reduction in exercise pace, possibly representing a form of behavioural thermoregulation to improve thermal compensability.[8]

Similar divergences in pacing between top-finishers and lesser-placed finishers has previously been presented for athletes in cooler conditions (from 5-21°C) with a ~2 minute differential between the first and final 5 km split for athletes finishing in the 25th and 50th positions.[25] Our data extend these observations to an elite cohort under conditions of extreme heat and humidity, which resulted in a more pronounced slowing; equivalent time differential of 05.09 ± 01.37 minutes. Thus, small errors in initial exercise pace are significant in terms of their overall influence on performance and this effect is magnified in extreme heat and humidity. It is also plausible that these extremes evoke extremes of emotion and amotivation, both factors suggested to control work rate as part of the interoceptive theory of pacing, increasing the likelihood of 'prediction errors' and sub-optimal pacing.[30] The influence of other competitors is also likely to be relevant; athletes adopt a higher initial exercise pace during exercise in the heat when they believe that they are competing against a superior athlete.[9] This observation, together with our analysis demonstrating world ranking was a significant predictor of performance in Doha, suggests that lesser-ranked runners attempted to maintain pace with superior runners resulting in a pace that evoked a psychophysiological deficit and exceeded their abilities. Ultimately this early aggressive pace proved unsustainable. The low level of variance explained by our predictor variables also highlights the significant behavioural component to exercise pacing.[8] Finally, our analysis also indicated there was no difference in the initial pacing profile adopted by finishers and non-finishers, although the initial pace of non-finishers (95.0 ± 2.7% of PB in first 5 km) was more in keeping with the (sub-optimal) pacing of athletes finishing outside the top-positions (95.4 ± 2.3% of PB). Nevertheless, this observation, in combination with the fact that most withdrawals (93%) occurred within the first 15 km of the event, is not consistent with 'catastrophic' pacing and suggests that pacing alone does not explain the high failure rates.

Practical Applications

Events with unprecedented dropout rates due to environmental extremes warrant detailed examination to explain the aetiology this failure. We show differences in the exercise pacing across sub-groups completing Doha 2019 women's marathon. Pre-race advice, particularly for the less experienced and lower ranked runners, should include adopting a more conservative pace early on to optimise performance and increase likelihood of completion.

Conclusion

In summary, amongst elite athletes undertaking a marathon in extreme heat and humidity there was reduced performance, progressive slowing of pace and high-non-completion rate, compared to a cohort performing under cooler conditions. Performance in the heat was not related to characteristics known to favourably influence heat exchange. Instead, the athletes who performed best adopted a more conservative initial pacing strategy (behaviour), consistent with a theoretical bioenergetic optimum. Athletes in lower finishing positions, and non-finishers, adopted a more ambitious earlier exercise pace, which was subsequently unsustainable.

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Table Legends

Table 1. Descriptive summary finishing time data (mean ±SD, median, range and 95% CI) of athletes who finished the Doha 2019 (n=40) and London 2017 (n=78) Women's IAAF World Championship marathons.

Table 1 Mean (±SD) running pace (km.h^{-1}), percentage of personal best (PB), for stratified finisher Groups 1, 2, 3 and 4 at the 2019 and 2017 IAAF World Championship women's Marathon in Doha (n=40) and London (n=40); * indicates all groups different *within* variable *within* marathon.

Figure Legends

Figure 1. Mean ±SD 5km running pace (km.h^{-1}) for the IAAF World Championships women's marathon in Doha 2019 (n=40) and London 2017 (n=78); $\overset{*}{\longleftrightarrow}$ = different at each distance marker *between* marathons, --- with "ns" and --- with "*" indicates no difference or significant difference respectively between consecutive points *within* London and Doha data indicative of end spurt.

Figure 2. Mean ±SD and relative (percentage of PB) running pace in stratified Groups 1(A), 2(B), 3(C) and 4(D) at the IAAF World Championship women's marathon in Doha 2019 (n=40) and London 2017 (n=40); * indicates difference between marathons.

Figure 3. Mean ±SD running pace expressed as a percentage of personal best (PB) at 5km and 10km for finishers (n=40) vs non-finishers (n=26) at the IAAF World Championship women's Doha 2019 marathon; ns = no difference between groups at 5km and 10km.