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Authors: Arthur H. Bossi[1], Guilherme G. Matta[2], Guillaume Y. Millet[3], Pedro Lima[2], Leonardo C. Pertence[2], Jorge P. de Lima[2], and James G. Hopker[1]

Affiliations: [1]School of Sport and Exercise Sciences, University of Kent, Chatham Maritime, Chatham, Kent, England. [2]Faculdade de Educação Física e Desportos, Universidade Federal de Juiz de Fora, Juiz de Fora, Minas Gerais, Brazil. [3]Human Performance Laboratory, University of Calgary, Calgary, Alberta, Canada.

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[1] School of Sport and Exercise Sciences, University of Kent, Chatham Maritime, Chatham, Kent, England.

[2] Faculdade de Educação Física e Desportos, Universidade Federal de Juiz de Fora, Juiz de Fora, Minas Gerais, Brazil.

[3] Human Performance Laboratory, University of Calgary, Calgary, Alberta, Canada.

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Correspondence:
Arthur Henrique Bossi
School of Sport and Exercise Sciences
University of Kent at Medway
Medway Building
Chatham Maritime
Chatham, Kent
ME4 4AG
England
asnb3@kent.ac.uk
+44 (0)7398 944056

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Abstract

Purpose: To describe pacing strategy in a 24-h running race and its interaction with sex, age group, athletes' performance group and race edition. **Methods:** Data from 398 male and 103 female participants of 5 editions were obtained based on a minimum 19.2-h effective-running cut-off. Mean running speed from each hour was normalised to the 24-h mean speed for analyses. **Results:** Mean overall performance was 135.6 ± 33.0 km with a mean effective-running time of 22.4 ± 1.3 h. Overall data showed a reverse J-shaped pacing strategy, with a significant reduction in speed from the second last to the last hour. Two-way mixed ANOVAs showed significant interactions between racing time and both athletes' performance group ($F = 7.01$; $P < 0.001$; $\eta_p^2 = 0.04$) and race edition ($F = 3.01$; $P < 0.001$; $\eta_p^2 = 0.02$), but not between racing time and both sex ($F = 1.57$; $P = 0.058$; $\eta_p^2 < 0.01$) and age group ($F = 1.25$; $P = 0.053$; $\eta_p^2 = 0.01$). Pearson's product-moment correlations showed an inverse moderate association between performance and normalised mean running speed in the first 2 h ($r = -0.58$; $P < 0.001$) but not in the last 2 h ($r = 0.03$; $P = 0.480$). **Conclusions:** While the general behaviour represents a rough, reverse J-shaped pattern, fastest runners start at lower relative intensities and display a more even pacing strategy than slower runners. The 'herd behaviour' seems to interfere with pacing strategy across editions, but not sex or age group of runners.

Keywords: ultraendurance; work distribution; competitive behaviour; gender; track and field.

Introduction

In order to achieve the best performance outcome in endurance competitions, athletes must efficiently regulate their exercise work rate, i.e. adopt a pacing strategy [1,2]. With the growth in popularity of ultramarathons [3-6], a few studies have investigated pacing strategies in extreme distances ranging from 100 to 161 km [7-13], but none has done so in a 24-h running race. Besides the latter being longer—at least for well-trained athletes—time-based races might potentially affect how runners pace their efforts [14].

A well-cited review suggests during prolonged endurance events athletes achieve optimal performance when an even pacing strategy is adopted [1]. Indeed, Lambert et al. [9] showed although most athletes chose a positive pacing strategy during a flat course 100-km ultramarathon, the fastest times were associated with fewer changes in running speed during the race. Likewise, Knechtle et al. [10] observed the first 10 runners to finish a hilly 100-km ultramarathon showed fewer reductions in mean running speed during the last third of the race. Hoffman [8] investigated pacing strategy during a mountainous 161-km ultramarathon and found despite wide variations in running speed due to varying gradient, fastest times were achieved by athletes more able to limit speed fluctuations. Whether pacing strategies outlined above are also reflective of longer-duration, time-based events—such as 24-h running races—is yet to be determined. In fact, two recent studies [11,12] suggest previous results cannot be taken as conclusive. Tan et al. [11] revealed a reverse J-shaped pacing strategy in 101- and 161-km races whereas Renfree et al. [12] demonstrated an 'inverse sigmoid' profile in a 100-km race.

Many studies have also investigated how sex [3-5,12,15-19], age group [3,4,6,10,12,13,15-18] and race edition [3,7,8,10,17] interact with performance and/or pacing strategies in both marathon and ultramarathon-distance running. For example, women are considered better pacers than men because they usually slow down less in the second half of marathon [15-17] and ultramarathon [12] running races; presumably due to physiological [15,17,20,21] and/or psychological [12,16,22] differences. Whether women will outrun men in ultra-marathon distances has also been a long-standing debate [5,18,19]. Moreover, studies have demonstrated fastest athletes in ultramarathon running are master competitors (>35 years old) [3,4,6,10], likely due to many years of specific training and races completed [4,6,10]. Coincidently, older runners are also considered better pacers than youngers, both in marathons [15] and ultramarathons [10,13]. Lastly, pacing strategy has been shown to differ across race editions [7,8,10,17], possibly due to dissimilar weather conditions [2,7,8,17] or tactical decisions of the leaders—when runners choose to follow the leading competitors at the beginning of the race [11,12]. Although these variables seem to be generally relevant to pacing strategy in long duration events, it is unclear which patterns may be found in a time-based, 24-h running race.

Thus, the purpose of this study was to investigate the overall pacing strategy in a 24-h ultramarathon-distance running race and its interaction with sex, age group and athletes' level of performance. In addition, variation among different race editions was studied. We hypothesised a more even pacing strategy would be found in the fastest runners, women, and older runners. We also hypothesised each race edition would display a particular pacing strategy.

Methods

Racing data and participants

This study was determined by our institution to be exempt from institutional review board approval since it involved analysis of online, publicly available data. Race organizers were contacted and we collected and analysed data from the Ultramaratona Rio 24 h – Fuzileiros Navais; an ultramarathon-distance running race held on an athletics track at the Naval Academy in Rio de Janeiro – Brazil (altitude: 6 m). Starting at 09:00 am, the event required athletes to run around the 400-m track for 24 h with the aim of achieving the greatest possible distance. Times and distance were recorded by an electronic chip timing system (Transponder, Corpore, São Paulo, Brazil) attached to the runner's shoelace. The running direction around the track was changed every 2 h and runners could consume food and/or beverages ad libitum, from a buffet provided by the organizer or by their supporting team. The mean (range) ambient temperature and humidity recorded were: 22ºC (20º – 25ºC) and 90% (78 – 100%); 29ºC (26º – 32ºC) and 76% (62 – 89%); 22ºC (21º – 24ºC) and 82% (73 – 88%); 22ºC (19º – 26ºC) and 64% (44 – 78%); 21ºC (19º – 23ºC) and 77% (69 – 88%); respectively for 2008, 2009, 2010, 2011 and 2012 race editions (http://www.weather.org).

Study design

Hour-by-hour and final results of the race were obtained from the official race website (http://www.corpore.org.br). Initially, data from 751 athletes (613 males and 138 females) within 5 consecutive editions (2008 to 2012) were gathered for this study. After consulting previous research involving 24-h running trials [23,24], we found the effective time spent running or walking was 18 h 39 ± 41 min. Thus, in order to eliminate the runners not aiming to complete the entire race, we imposed a 19.2-h (80% total duration) minimum cut-off on our data. Consequently, 250 athletes (215 males and 35 females; 86% and 14%, respectively) who ran less than 19.2 h were excluded from our analysis.

The remaining 501 runners were ranked into 4 performance groups (i.e. first, second, third and fourth quartile of finishers) based upon total distance covered: group 1 (125 fastest runners, covering a mean distance of 180.5 km), group 2 (126 fast runners, covering a mean distance of 142.4 km), group 3 (125 medium runners, covering a mean distance of 122.1 km) and group 4 (125 slowest runners, covering a mean distance of 97.2 km). In 3 more distinct analyses, the 501 athletes were split into 6 age groups (i.e. 20–29, 30–39, 40–49, 50–59, 60–69, and 70+ years), separated by sex or race edition. Men comprised 79.4% (n = 398) and women 20.6% (n = 103) of the final sample.

Statistical analysis

We compiled a database of each race edition including runners' sex, age group, finish time, effective-running time, total distance covered, number of completed laps, final classification and mean running speeds from each 1-h period. To investigate overall pacing strategy and interactions with sex, age group, performance group and race edition, the mean running speed from each hour was percentage normalised to the mean running speed of the 24 h. This procedure was used in order to eliminate the effect of differences in absolute running speed among runners [25].

Overall runners' pacing strategy was assessed from normalised mean running speeds using one-way repeated-measures ANOVA with Bonferroni pairwise comparisons. To analyse differences in pacing strategies, two-way mixed ANOVAs were performed with sex, age group, performance group and edition as fixed factors; and a focus on the interaction effect. Since data were previously percentage normalised, between-subject main effects would be null. Tukey's HSD post hoc tests were used to identify group differences at each time interval. Effect sizes were calculated as partial eta-squared (η_p^2). Best-fit quadratic regressions of racing time vs. normalised mean running speed were calculated for each performance group, assuming a parabolic-shaped pacing strategy. Finally, in line with the '10–80–10' work distribution concept [2], Pearson's product-moment correlations were used to assess the relationship between total running distance and normalised mean running speed from the first and the last 2 h (n = 501). Data analysis was performed using SPSS statistical package (20.0, IBM, Armonk, USA) and statistical significance was set at $P \leq 0.05$.

Results

Results are presented as mean ± SD. Distance covered by athletes in all editions was 135.6 ± 33.0 km, with an effective-running time of 22.4 ± 1.3 h. Eleven athletes (2.2%) performed 24 h of effective running (8 males and 3 females). Men achieved a mean running distance of 136.3 km (5.68 ± 1.38 km·h^{-1}) and women 132.7 km (5.53 ± 1.34 km·h^{-1}), a difference of 2.6%. When the 10 best overall performances were compared, men achieved 220.8 km (9.2 ± 0.3 km·h^{-1}) and women 201 km (8.37 ± 0.58 km·h^{-1}), a difference of 9%. Table 1 and Figure 1 present descriptive data separated by race edition and age group, respectively. The largest participation was by athletes in the age group of 40–49 years, comprising 178 athletes (35%), of which 133 (74.7%) were men and 45 (25.3%) women.

Overall analysis (n = 501) demonstrated runners generally adopt a reverse J-shaped pacing strategy with a decrease in speed in the last hour (F = 470.09; P < 0.001; η_p^2 = 0.48; Figure 2). In addition, significant interactions were found between racing time and athletes' performance group (F = 7.01; P < 0.001; η_p^2 = 0.04; Figure 3). The main pairwise comparisons (i.e. group 1 compared with the others) were significant at many time points (P ≤ 0.05).

Best-fit quadratic regressions of racing time vs. normalised mean running speed were calculated for each performance group and produced high coefficients of determination (all P < 0.001) for the following equations—performance groups 1–4, respectively:

$$NMRS = 0.176h^2 - 6.71h + 148.123 \ (r^2 = 0.96) \quad (1)$$
$$NMRS = 0.264h^2 - 9.595h + 166.138 \ (r^2 = 0.94) \quad (2)$$
$$NMRS = 0.238h^2 - 9.379h + 168.245 \ (r^2 = 0.93) \quad (3)$$
$$NMRS = 0.362h^2 - 12.265h + 177.424 \ (r^2 = 0.90) \quad (4)$$

where NMRS is the normalised mean running speed and h is the racing hour (1–24).

Significant interactions were also found between racing time and edition (F = 3.01; P < 0.001; η_p^2 = 0.02; Figure 4), but not between racing time and sex (F = 1.57; P = 0.058; η_p^2 < 0.01; Figure 5), and racing time and age group (F = 1.25; P = 0.053; η_p^2 = 0.01; Figure 6).

Finally, an inverse moderate correlation was found between total running distance and normalised mean running speed in the first 2 h (r = -0.58; P < 0.001) but not in the last 2 h (r = 0.03; P = 0.480).

Discussion

The main finding of this study was that, regardless of sex, age group, athletes' performance group or race edition, runners displayed a rough, reverse J-shaped pacing strategy. They reduced speed during most of the race but slightly increased in the final hours; except in the very last one, when they reduced speed again. In addition, the best runners revealed a more conservative pacing strategy in the first hours compared with their slower counterparts.

General Pacing Strategy and Performance Group Differences

Most athletes completed the initial 8 hours fast—relative to their mean race speed—but slowed progressively from the beginning until 19 h. Then, they sped up during the final hours of the race, except in the last hour, when they significantly reduced their speed. Our results corroborate the findings of Tan et al. [11], who revealed a reverse J-shaped pacing strategy in 101- and 161-km races, but they are not a unanimity. Interestingly, Renfree et al. [12] demonstrated an 'inverse sigmoid' profile in a 100-km race, but they did not discuss this outcome. Perhaps, this discrepancy stems from the time needed to complete each race and reflect the performance level of the samples: 17.5 to 25 h and 25 to 31.5 h respectively for the 101- and 161-km categories in one study [11] (similar to our pacing profile); and 6.5 to 12 h for 100 km in the other [12] (different).

Indeed, significant differences in normalised mean running speed were found among performance groups. In accordance with previously published data [8-12,15-17], the fastest runners (group 1) displayed a more even pacing strategy compared with slower competitors—i.e. a more conservative initial speed (mainly in the first 3 h), slowing down less as the race progressed. In contrast, slower runners (groups 2, 3 and 4) were unable to maintain their initial speed as much as the fastest runners, reducing their speed more quickly, as well as displaying the greatest speed fluctuations throughout the race. In addition, athletes in group 1 ran faster than the other groups mainly in the 13 to 21-h interval, although the differences were not always statistically significant. Of note, the inverse moderate correlation between normalised mean running speed of the first 2 h and distance completed in 24 h strengthens the link between pacing strategy and performance [1]. Usefully, the regression analysis reflected each group's behaviour and produced equations with high coefficients of determination, which can be employed to predict running intensity or to develop racing tactics.

Given the retrospective nature of our data, we do not have physiological evidence to provide any conclusions as to why these pacing strategies might be. Considering previously published literature, we could speculate a role of fatigue in determining a reverse J-shaped pacing strategy [1,2,26]. In 24-h race simulations on a treadmill, speed declined regularly from the beginning until 16 h (similar to our study) and remained constant afterwards (different) [23,24]. Martin et al. [23] showed a large maximal muscle torque reduction after the 24-h trial and an increase in ratings of perceived exertion (RPE)—from the beginning until 16 h, tending to plateau around 15 points afterwards. Concomitantly, Gimenez et al. [24] showed an increase in oxygen uptake until 8 h, again, followed by a plateau. It is possible their runners lacked the real competitive motivation to increase RPE (and speed) in the final hours [27]. In fact, in our study athletes tended to increase exercise intensity after 19 h, except in the last hour. If the final ranking was already set at 23 h, some athletes may have preferred to finish at a slower pace in order to limit overexertion [27]. Cramps, for example, have been frequently reported [28], which might have contributed for an imperfect parabolic pacing strategy.

The presence of a 'herd behaviour' (i.e. athletes following the leader and running in small groups) [29] has been often discussed in previous studies [11,12]. This behaviour was probably facilitated by the course nature of the race we investigated (i.e. 400-m track). Slowest athletes that chose to follow the fastest runners at the first 3 h, even after being overlapped, might have increased speed beyond their sustainable intensity for the race duration. Consequently, fatigue ensued prematurely and speed was reduced all over the race—as we observed in performance groups 2, 3 and 4. Indeed, a recent study provides evidence that the opponents' behaviour affects pacing decisions [30].

Different Editions

It has been shown runners adopt unique pacing strategies in different editions of the same race [7,8,10,17]. Changes in pacing strategy due to distinct environmental temperatures have been repeatedly demonstrated [1,2,7,8,17]. However, psychological factors like whether or not to follow what other athletes do may also play a role [11,12]. Indeed, with the exception of 2009, which registered the highest mean temperature and the lowest effective-running time, weather was fairly consistent across race editions (21º–22º vs. 29ºC). Since we still found a significant interaction between racing time and edition, we believe the herd behaviour explain most of the discrepancies in pacing strategy among editions.

Importantly, in 2011, the greatest effective-running time led to the shortest distance covered. This edition had the highest number of participants, which may have caused congestion on the track, disrupting the fastest runners' ability to achieve long distances. This fact might be another reason. As the race started at the same time of the day in every edition, any potential circadian rhythm effects [31] on pacing strategy are discarded.

Sex Differences

The current study agrees with others [5,18,19] and gives no clue women will outrun men in ultramarathon-distance running races. Despite men and women differed at only 2.6% in overall performance, this difference increased to 9% when analysed the 10 best performances during the study period. Similarly, Peter et al. [5] analysed sex differences in 24-h running races from 1977 to 2012 and found a 4.6% mean difference—which also increased to 12.9% when taken the 10 fastest women and men ever. This trend possibly reflects psychological sex differences such as in confidence levels, attitude towards risk and competitiveness [12,16,22]. While only the fittest women might be willing to train for and compete in very long races, less trained men might be equally motivated [22]. In fact, after limiting our sample to restrict analysis to athletes aiming to complete the entire race, 14% of the excluded runners were females, while females composed 20.6% of the final sample.

Interesting, however, our results showed no significant interaction between racing time and sex, suggesting women adopt similar pacing strategies as men. This finding is converse to what has been reported [12,15-17]. Renfree et al. [12] showed males reduced intensity more from start to finish than females in a 100-km ultramarathon running race. Likewise, women typically slow down less than men in the second half of marathon races [15-17]. This sex difference in pacing strategy is often hypothesised to be a consequence of physiological [15,17,20,21] or the aforementioned psychological sex differences [12,16,22]. However, since we are the first to analyse sex differences in pacing strategy from a time-limited running race, we question whether either hypothesis holds true. Indeed, Abbiss et al. [14] showed the nature of exercise task—time-based or distance-based—impacts work distribution. Together with the sex difference in performance [5,18,19] (which means pacing strategy is affected by longer completion time for women in fixed-distance races), these facts might explain the contradiction between our and other studies [12,15-17]. The 400-m track and the occurrence of a herd behaviour could have influenced our findings, though.

Age groups

Some authors [3,4,6,10] pointed out the fastest finishers in ultramarathon races are master runners (>35 years old), and many years of specific training and races completed [4,6,10] are probably what they have in common with few exceptions to this rule (e.g. Kilian Jornet, Scott Jurek). Since previous experience is believed to influence pacing strategy [1,2,32], it is not surprising that older runners are also considered better pacers than youngers in long distance events [10,13,15].

However, we did not find differences in pacing strategy between age groups. Perhaps, the age categories with 10-year range limited the resolution of our data. For example, in a 100-km ultramarathon race, Knechtle et al. [10] analysed 5-year age categories (18–24, 25–29, etc.) and found young runners (18–24 years old) showed greater speed fluctuations and slower finishing times than master runners (>35 years old). Interestingly, Renfree et al. [12] adopted 5-year range as well, but, like us, did not find differences in pacing strategy between age groups. They did not analyse young athletes (in their twenties) as an exclusive group, though. Since age has actually been analysed as a proxy for training and racing experience [4,6,10,12,13,15], an experimental approach is recommended for this dilemma solution.

Practical Applications

The findings of this study could be useful for athletes and coaches aiming to develop optimal pacing strategies for ultramarathon-distance running. Data suggest starting with conservative speeds and limiting speed fluctuations along the race should be considered for achieving the best performance outcome. Moreover, the equations produced by the regression analysis may be useful in predicting race outcomes according to athlete's level and pacing strategy adopted—leading to better race tactics. However, athletes still need to experiment until prospective repeated-measures studies test the relationship between experience, pacing strategy and performance in ultramarathon running. Also, whether the presence of fast runners could influence work distribution and final performance of slower competitors is yet to be determined. The scientific literature is replete with observational studies in ultramarathon running and we urge authors start thinking about the next step.

Conclusion

In summary, this study shows that in a 24-h ultramarathon-distance running race athletes adopt a reverse J-shaped pacing strategy with minor deviations from this pattern; such as in the very last hour, when they reduce effort relative to the previous one. In accordance with our hypothesis, the fastest runners start at a lower intensity (relative to their mean race speed) and display a more even pacing strategy compared with slower opponents. In contrast to our hypothesis, sex and age group did not influence pacing strategy in a time-based, 24-h running race. Finally, despite a reverse J-shaped pattern was evident across the different editions of this ultramarathon, minor changes in pacing strategy did happen, possibly reflecting a unique set of tactical decisions made by runners in each edition.

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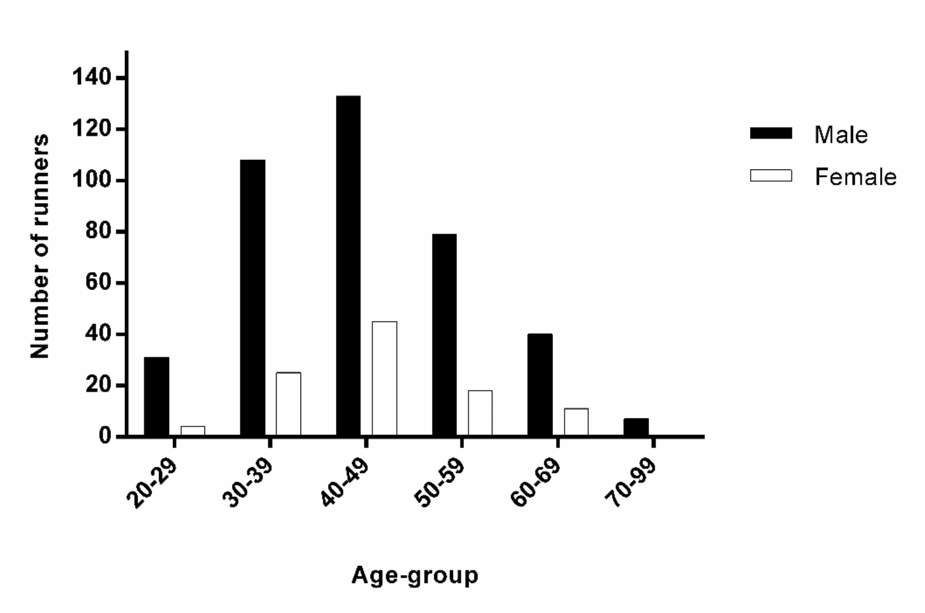

Figure 1 – Number of men and women at each age group.

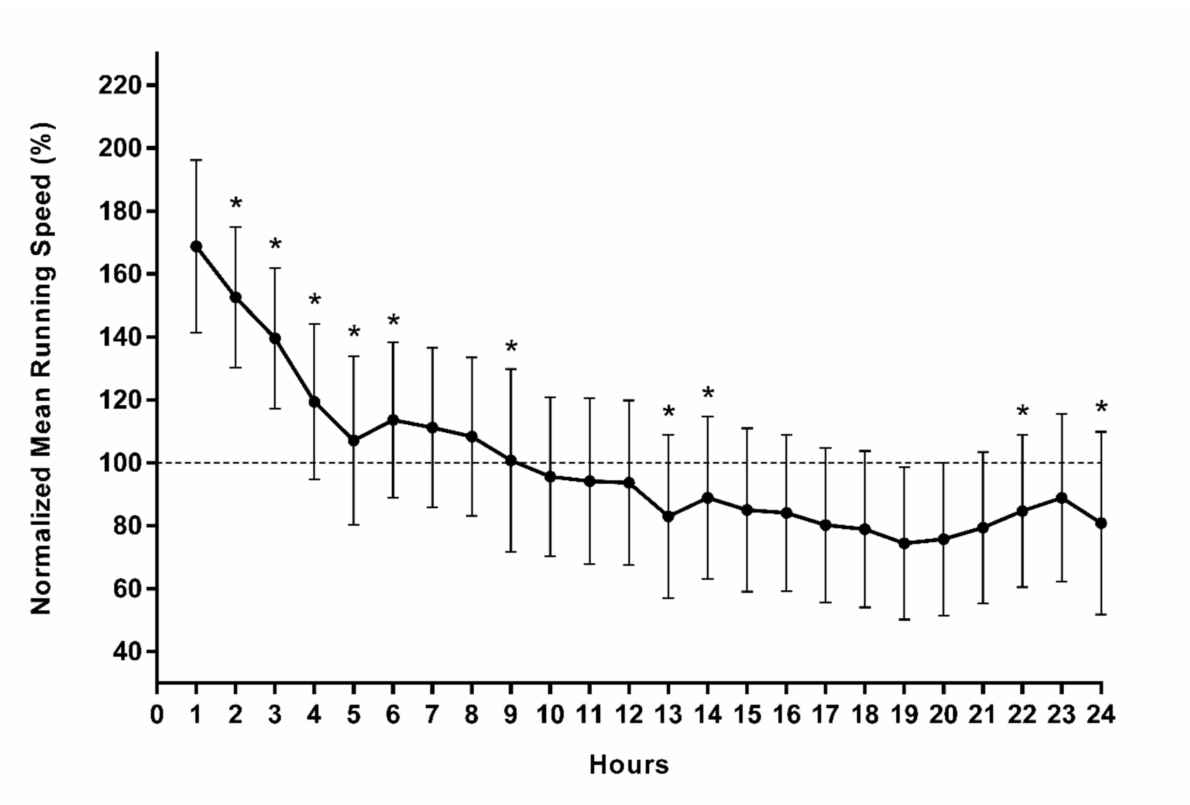

Figure 2 – Overall pacing strategy adopted by all runners, in all editions. *Significant different from the previous hour ($P \leq 0.05$).

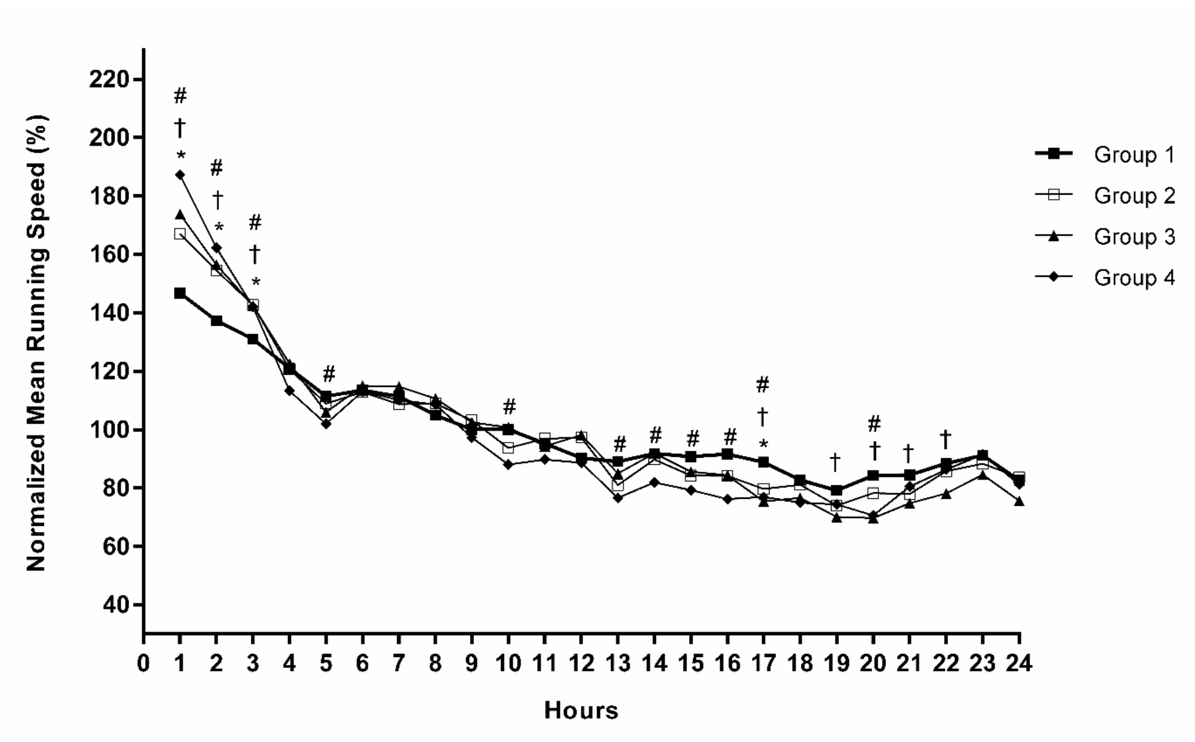

Figure 3 – Pacing strategy adopted by performance groups. Groups 1, 2, 3 and 4 achieved a mean distance of 180.5, 142.4, 122.1 and 97.2 km, respectively. Significant normalised mean running speed vs. time interactions were found ($F = 7.01$; $P < 0.001$; $\eta_p^2 = 0.04$). *Significant difference between groups 1–2; †significant difference between groups 1–3; #significant difference between groups 1–4.

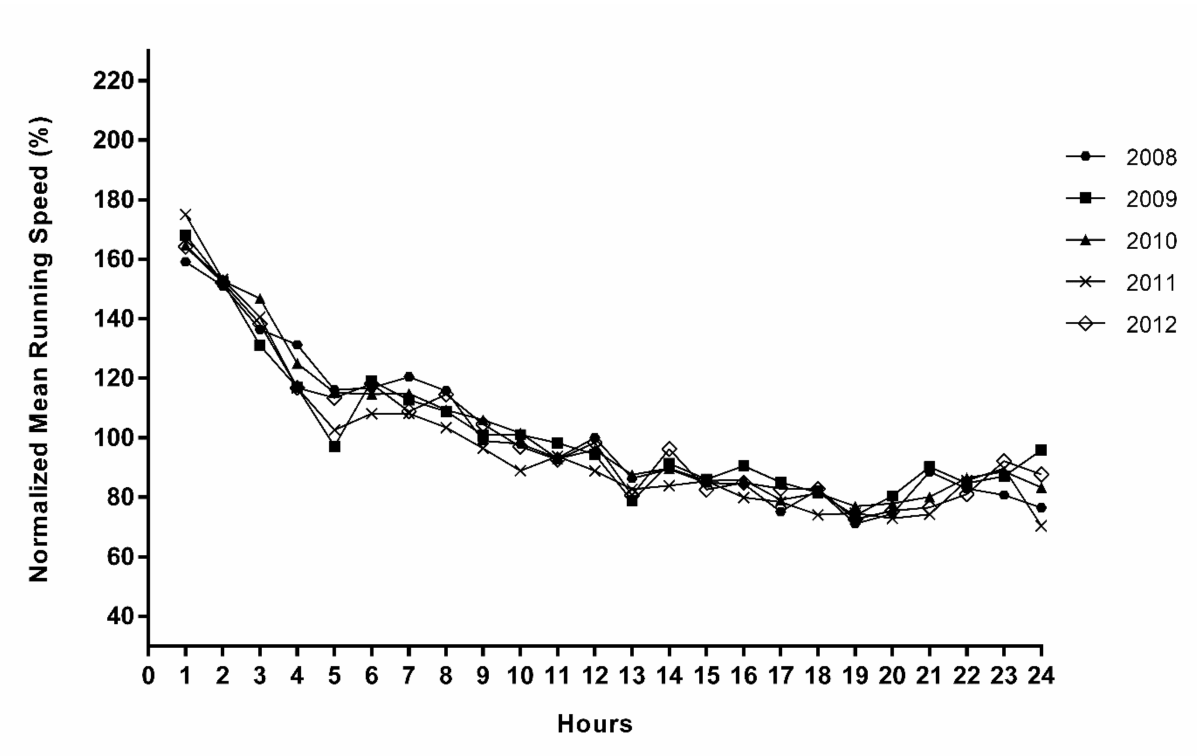

Figure 4 – Pacing strategy adopted by runners in each race edition. Significant interactions were found between racing time vs. edition ($F = 3.01$; $P < 0.001$; $\eta_p^2 = 0.02$).

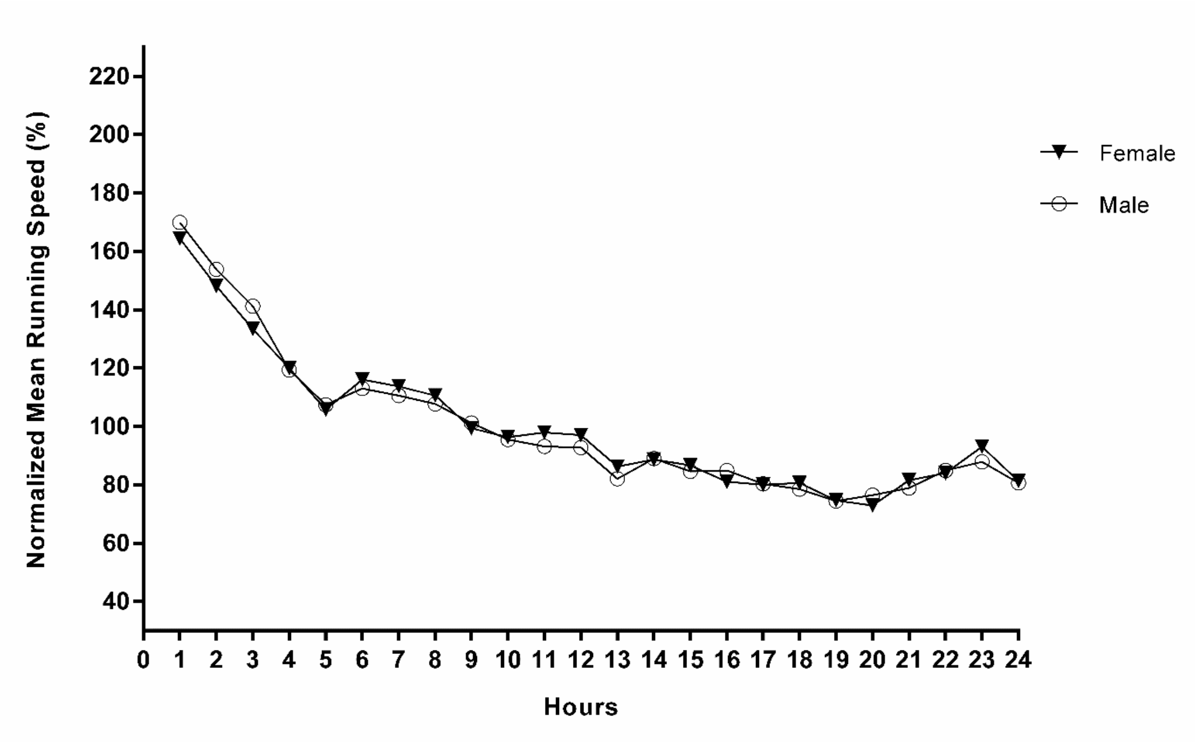

Figure 5 – Pacing strategy adopted by males and females.

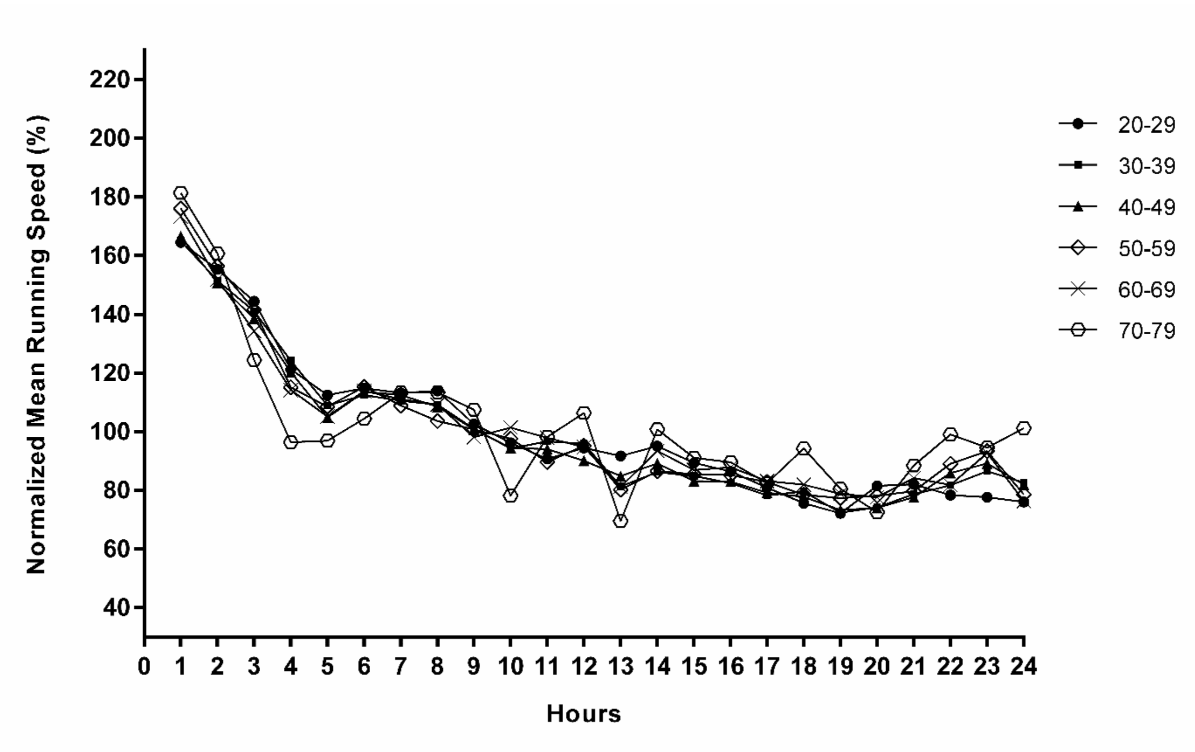

Figure 6 – Pacing strategy adopted by runners of different age groups.

Table 1 – Number of participants, mean completed distance and mean effective-running time of each race edition.

Edition	n	Mean Distance (km)	Mean Running Time (h)
2008	30 (19 M; 11 F)	150.5 ± 27.0	22.0 ± 1.4
2009	84 (70 M; 14 F)	134.0 ± 28.8	21.6 ± 1.3
2010	108 (86 M; 22 F)	136.4 ± 30.6	22.4 ± 1.3
2011	191 (155 M; 36 F)	129.0 ± 32.1	23.2 ± 1.3
2012	88 (68 M; 20 F)	145.3 ± 32.5	21.8 ± 1.3
Total	501 (398 M; 103 F)	135.6 ± 33.0	22.4 ± 1.3

M: males; F: females.