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Influence of Sex, Athletic Category and Athletic Level on Marathon Pacing Strategy: An Analysis of the Trinidad Alfonso EDP Valencia Marathon From 2014 to 2023

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ABSTRACT

The main objective of this study was to analyse the evolution of pacing in the Valencia Marathon from 2014 to 2023 in relation to sex, age and athletic level. A total of 146,108 runners were included in this study, grouped into 10 athletic categories and eleven performance level categories. Pacing was assessed through nine race segments, each covering a 5 km split. All data were obtained from the official website. Absolute speed (m/s) and relative speed per segment were calculated for each section, along with the coefficient of variation (CV) in speed and other variables such as hitting the wall (HTW). The results indicate that the 2022 and 2023 editions showed the highest percentages of even pacing (EP) and the lowest values for CV, HTW and marathon finishing time. Women showed a higher percentage of EP than men (77.6% vs. 74.3%, $p < 0.001$), lower CV values (6.79 ± 5.14% vs. 7.40 ± 5.43%, $p < 0.001$) and a higher prevalence of HTW. A significant decrease in EP percentage was observed starting from the M55 category in men and the F45 category in women. Among male and female runners who finished the marathon in under 3 and 3 h 15′, respectively, both EP and HTW percentages decreased significantly. A significant correlation was observed between marathon time and CV of speed ($r = 0.551$ and $p < 0.001$). In summary, the results of this study confirmed the effect of sex, age and athletic level on pacing strategy.

1 | Introduction

In recent years, the motivation to adopt a healthy lifestyle has increased. Consequently, the popularity of recreational sports, such as running, has grown, and these activities have gained widespread acceptance (Menheere et al. 2020). Accordingly, running has become an immensely popular pastime pursued in the public sphere by millions of recreational participants worldwide (Scheerder et al. 2015). The popularity of running is due, among other factors, to the satisfaction of physical and psychological health needs, goal achievement, tangible rewards, social influences and easy availability (Salas Sánchez et al. 2013). Achievement motives, such as competition with other runners and personal goal achievement, are also important motivations—for example, mid-level experienced runners, after their second or third marathon, were mainly motivated by personal performance enhancement and psychological rewards (Zach et al. 2017). Therefore, not only finishing the marathon but also improving one's personal best are essential performance motivations for all runners during the race.

Summary

- Participants adopted an even pacing strategy and displayed an end spurt.
- The edition year, sex, category and athletic level influence marathon performance and pacing profile.
- The last editions showed the best overall times, with the highest percentages of athletes showing even pacing and the lowest coefficient of variation values in speed.

There are several factors that predict endurance running performance. These include physiological variables, such as maximum oxygen uptake (VO_2max) and running economy (Mclaughlin et al. 2010), and biomechanical factors linked with mechanical efficiency (Moore 2016). However, factors related to motor control have not been analysed in depth. In this regard, endurance performance involves the prolonged maintenance of constant or self-regulated power/velocity (Pageaux and Lepers 2016). For example, athletes have to make decisions about how and when to invest their energy for an optimal performance; this process is known as 'pacing' (Smits et al. 2014). Pacing control is related to several interoceptive and exteroceptive variables such as psychological factors (e.g., motivational state and knowledge about the endpoint), physiological factors (e.g., heart rate), biomechanical factors (e.g., body posture) and environmental factors (e.g., climate) (Latorre-Román et al. 2020). Therefore, pacing strategies differ according to the length of the athletic competition, the environment in which it is performed, the motivation of the runner, the knowledge and experience of the athlete and the physical fitness of the runner (St Clair Gibson et al. 2006).

Athletes can make wrong decisions, using conservative strategies or unsustainable work rates that lead to decreased performance (Renfree et al. 2014). Some athletes suddenly reduce their speed in the mid portion of the race, whereas other athletes will perform great accelerations in the middle of the race or at the end of it (de Koning et al. 2011). Several pacing profiles have been identified during athletic competition: (a) even pacing (EP) (i.e., a constant speed); (b) positive pacing (i.e., decreasing in speed over time); (c) negative pacing (i.e., increasing in speed over time); (d) all-out pacing (i.e., maximal possible speed from the start); (e) variable pacing (i.e., significant race speed fluctuations) and (f) parabolic-shaped pacing (i.e., positive and negative pacing in different segments of the race), with no unanimous conclusion being drawn as to which one is the most optimal in all competitions (Abbiss and Laursen 2008). There is no agreement on the best pacing strategy for all runners and race types, above all because pacing is a complex process influenced by several factors (Pryor et al. 2020), such as sex, age, athletic level, environmental conditions, training methodology, marathon experience, phase of the competition and interaction with rivals (Deaner et al. 2015; Ristanović et al. 2023; Santos-Lozano et al. 2014; Swain et al. 2020).

The pacing tactics of the best marathon runners in the world have changed over the last 50 years, and although a negative pace strategy has been suggested as the most effective selection, a pacing strategy characterised by very few speed changes across the entire race may be the technique to drive in the future (Díaz et al. 2018). Similarly, previous studies suggest that more successful runners show less variability in their speed during 5 km splits than less experienced runners (Renfree et al. 2014; Santos-Lozano et al. 2014). In this regard, EP within marathons has been linked with faster marathon performance times (Swain et al. 2020). However, in the Vienna City Marathon in 2017 (Cuk et al. 2019) and in the New York marathon (from 2006 to 2011) (Santos-Lozano et al. 2014), most of the runners exhibited positive pacing strategies. Conversely, in contemporary elite-standard marathons, more negative pacing profiles were adopted in championships among both men and women (Casado et al. 2024). Therefore, previous studies offer contradictory findings about ideal marathon pacing according to different variables such as sex, age and athletic level. Consequently, future studies on this topic are recommended.

Currently, few studies have analysed pacing in the same marathon over time and those that have generally been conducted on elite runners (Muñoz-Pérez et al. 2023; Nikolaidis and Knechtle 2017; Santos-Lozano et al. 2014). Consequently, little information is available in the literature regarding patterns displayed by recreational runners. Moreover, in the last four years, carbon-fibre plate shoes have enhanced marathon performance by improving running economy (Hunter et al. 2019), this could have influenced the pace profiles of the runners (Rodrigo-Carranza et al. 2021). Therefore, the main objective of this study is to analyse the evolution of pacing over the last 10 years in the Trinidad Alfonso EDP Valencia Marathon. In this analysis, the variables and methods for calculating pacing from the most recent literature have been incorporated as well as various explanatory factors of pacing such as sex, age, athletic category and athletic level.

2 | Materials and Methods

2.1 | Participants

We initially took into consideration the official results and split times from finishers ($N = 215{,}563$) in the Trinidad Alfonso EDP Valencia Marathons (Spain) from 2014 to 2023. Due to the pandemic, the 2020 edition was only performed by professional athletes and therefore was excluded from the analysis. All data for this study were obtained from the website (https://www.facv.es/resultados/es) and included subject sex, runner category, finish time and each 5 km split time. The criteria for inclusion in the final database were as follows: having timing data for the half-race and the full race and the corresponding split times every 5 km and cases with a suspect time value in a section that suggested an error were removed. It was suspected that the split times were incorrect when the values indicated a speed greater or lower than 50% compared to the previous and subsequent segments or when the execution times or speeds were physically impossible—for example, less than 12 min for 5 km.

Finally, were considered a total of 146,108 runners for this study, including 122,543 men and 23,565 women. Athletes from 135 different countries participated in this study. Similarly to previous studies (Oficial-Casado et al. 2022; Weiss et al. 2022), participants were categorised depending on their time performance in the marathon in 11 categories: category 1 < 2:10, category 2 between 2:11 and 2:19, category 3 between 2:20 and 2:29, category 4 between 2:30 and 2:44, category 5 between 2:45 and 2:59, category 6 between 3:00 and 3:14, category 7 between 3:15 and 3:29, category 8 between 3:30 and 3:59, category 9 between 4:00 and 4:29, category 10 between 4:30 and 4:59 and category 11 > 5 h and > 5 h 29 in men and women, respectively. The women were categorised into a time category such as the men −1. In other words, category 2 for men was category 1 for women and so on. This study was performed according to the Declaration of Helsinki (2013 version) and it conformed to the Ethical Standards in Sport and Exercise Science Research (Harriss and Atkinson 2013).

2.2 | The Race

The Trinidad Alfonso EDP Valencia Marathon takes place from the middle to the end of November and the first week of December and has received the Platinum Label from World Athletics, formerly the International Association of Athletics Federations (IAAF), which places the marathon among the best marathons in the world, along with London, Berlin and New York. The Valencia Marathon presents relatively small changes in its elevation; indeed, it is considered one of the fastest marathons in the world because of the flat course and because its average ambient temperature was similar among the selected editions from 2014 to 2023 (Table 1).

2.3 | Procedures of Data Analysis

Data on split times for each participant were downloaded from the official website of the race, and the time required to complete each section was calculated in seconds. We calculated absolute speed (m/s) for each split (0–5 km, 5–10 km, … 35–40 km and 40–42 m) using the formula '5 km/split time' for all splits, except the last one where the '2.195/split time' was applied. The total finish time, the time for the first half marathon, the time for the second half marathon and the split times every 5 km were determined based on the chip times. At each 5 km checkpoint, each runner's chips crossed a digital receiver recording split times. Nine race lap splits were analysed (0–5, 5–10, 10–15, 15–20, 20–25, 25–30, 30–35, 35–40 and 40–42.2 km). The relative speed of each section for every runner was then calculated and presented as a percentage of the average speed for the full race (Díaz et al. 2018), using the formula = 100 x (speed of split—average race speed)/average race speed (Nikolaidis and Knechtle 2018b). In addition, eight points of change of speed (Δspeed, i.e., change of speed between two consecutive splits, in %) were considered: 5 km, 10 km, 15 km, 20 km, 25 km, 30 km, 35 km and 40 km, which we refer to as split speed cost (SSC) = 100 x (later time-previous time/previous time). Moreover, the variation in pace was analysed using the coefficient of variation (%CV) of the speeds, which was considered a metric of pacing, with lower values indicating a more consistent pace and vice versa (Nikolaidis and Knechtle 2018b). Additionally, to define the pacing profile, was used the method described by Deaner, Carter, Joyner, and Hunter (Deaner et al. 2015), which is calculated using the following formula: (% change = [second half time–first half time)/first half time] • 100). If the change was less than 10%, be it positive or negative, it was considered an EP. If the variation was greater than 10% negative, it was considered a positive profile, and if the variation was greater than 10% positive, it was considered a negative profile. Moreover, at the 30 and 35 km marks, the runners who experienced hitting the wall were those who ran these segments 7.3% slower than the average of the remaining 5 km segments of the race (Doherty et al. 2020). Finally, to analyse the final 2.195 km, the speed for this final segment was indicated as a percentage faster or slower than the speed between km 30 and km 40 (Nikolaidis et al. 2019) and was defined as an end spurt as Δspeed at 40 km > 0% (Nikolaidis and Knechtle 2017).

2.4 | Statistical Analysis

Data were analysed using SPSS, v.22.0 for Windows (SPSS Inc, Chicago, USA). The significance level was set at $\alpha < 0.05$. The data are shown in descriptive statistics for means, standard deviations and percentages. Tests of normal distribution and homogeneity (Kolmogorov–Smirnov and Levene's test, respectively) were conducted on all data before analysis. Differences

TABLE 1 | General characteristics of the different editions of the Valencia marathon.

Edition	2014	2015	2016	2017	2018	2019	2021	2022	2023
Men *n* (%)	10,005 (89.0)^{a}	8877 (91.6)^{b}	10,554 (88.5)^{a}	12,794 (85.9)^{c}	15,794 (82.9)^{d,e}	17,178 (81.3)^{f}	10,471 (84.1)^{e}	16,474 (81.8)^{d,f}	20,335 (79.4)^{g}
Women *n* (%)	1235 (11.0)^{a}	813 (8.4)^{b}	1367 (11.5)^{a}	2105 (14.1)^{c}	3247 (17.1)^{d,e}	3939 (18.7)^{f}	1978 (15.9)^{e}	3675 (18.2)^{d,f}	5267 (20.6)^{g}
All *n*	11,240	9690	11,921	14,899	19,041	21,117	12,449	20,149	25,602
Mean temperature (ºC)	15.8°	14.2°	15.4°	13.5°	17.7°	14.6°	13.2°	12.3°	10.8°
Humidity	68%	81%	61%	76%	74%	60%	54%	80%	58%
Accumulated altitude (metres)	46	46	91	91	74	74	79	78	76
Average wind speed (max.) (Km/h)	22	9	16	10	9	15	20	10	9

Note: Different superscript letters indicate significant differences ($p < 0.05$) between editions.

between sex were analysed using analysis of variance (ANOVA). Differences between marathon editions, categories and athletic level were analysed by ANOVA with repeated measures (group x measurement) for the dependent variables (absolute and relative speed and SSC). In addition, for all ANOVAs, Bonferroni post hoc test was performed. The relationship between categorical variables was analysed using contingency tables and the χ^2 test was applied. Binary logistic regression was used to identify predictors of the appearance of the HTW at kilometres 30 and 35. Moreover, a Pearson correlation analysis was performed between marathon time with CV, relative speed and SCC. The coefficient of variation (CV, %), given as a percentage SD/mean $\times$ 100, was calculated as a measure of speed variability.

3 | Result

Table 1 shows the general characteristics: participants, thermohygrometric conditions and the elevation gain of the different editions of the Valencia marathon analysed. The 2023 edition had the highest number of total participants and women finishing the race, with significant differences ($p < 0.05$) compared to the other editions. The environmental and orographic conditions were similar across all editions.

Figure 1 shows the evolution of the average marathon time of finishers in the analysed editions. A significant reduction ($p < 0.001$) in average time can be observed across all editions, both for men and women, as well as in the total sample. It can be observed that since 2021, average marathon times have consistently been lower than the overall average of all previous editions, indicating a sustained improvement in performance.

In all editions, the percentages total of pacing was as follows: EP = 74.8%, negative pacing = 3.6% and positive pacing = 21.6%. Women showing a higher percentage of EP than men (77.6% vs. 74.3%, $p < 0.001$). The analysis reveals a noticeable and sustained increase in EP from 2021 onwards. Prior to 2021, EP percentages ranged from 68% to 75%. However, since 2021, the percentage has consistently exceeded 77%. On the other hand, there is not enough statistical evidence to confirm that positive pacing has increased over the years. After 2016, negative pacing steadily declined again, reaching a low of 1.53% by 2023. Analysing the effect of the athletic category, both men and women, the younger categories ($M < 35$, M35 and M40) have a higher use of EP (~75%). In men, is from the M55 category onwards that EP decreases significantly, and it is also significantly lower in the $M < 23$ category; conversely, positive pacing increases. These findings are more pronounced in women, starting from the F45 category, although this is not the case for the $F < 23$ category. In terms of athletic level, it is among runners who take more than three hours to complete the marathon that the percentage of EP decreases significantly ($p < 0.05$) in relation to sub-three-hour athletes, with positive pacing increasing accordingly and negative pacing begins to emerge (Figure 2).

In general, taking into account the absolute speed of each marathon segment, the 5–10 km split is the fastest, whereas the 35–40 km split is the slowest. Regardless of the edition year of the marathon, a general decline in speed is consistently observed between kilometres 25 and 40. This decline becomes notably more pronounced among athletes at lower performance levels. Interestingly, the pattern also shows that this drop in pace affects both ends of the age spectrum: younger faster athletes tend to experience a sharp decrease due to early pacing, whereas older athletes often show a similar or even more pronounced decline. Additionally, the slowdown tends to be more marked among male participants. Although kilometre five is not the slowest point of the race overall, it is consistently slower than the average of other segments across all editions, sexes, performance levels and age categories. An end spurt is also commonly observed. However, it is less frequent among male runners compared to females (56.1% vs. 71.8%, respectively, $p < 0.001$) and less common in younger and middle-aged male groups (e.g., $M < 35$, M35, M40 and M45). The prevalence of end spurts increases as performance level decreases (e.g., Level 1 = 34% vs. Level 11 = 81.6%, $p < 0.001$) (Figure 3).

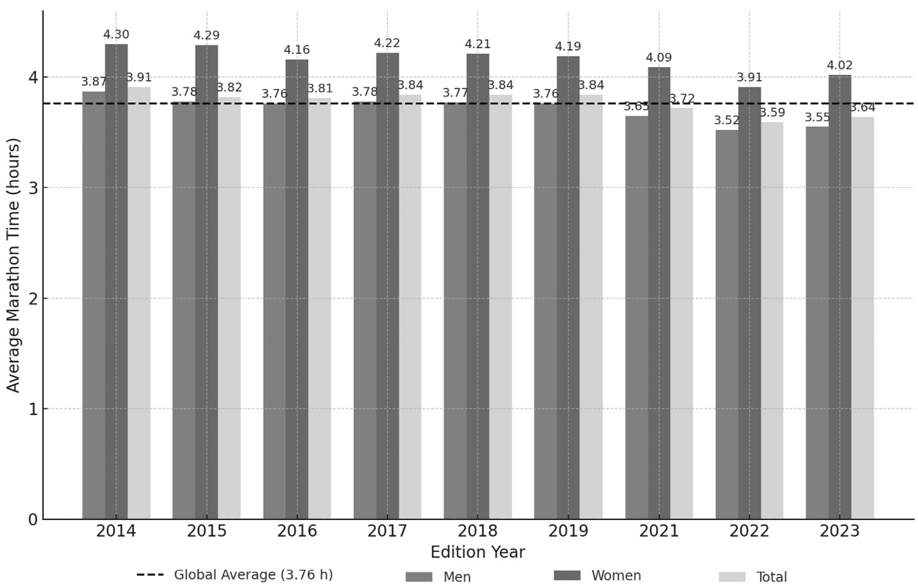

FIGURE 1 | Average marathon time by year and sex.

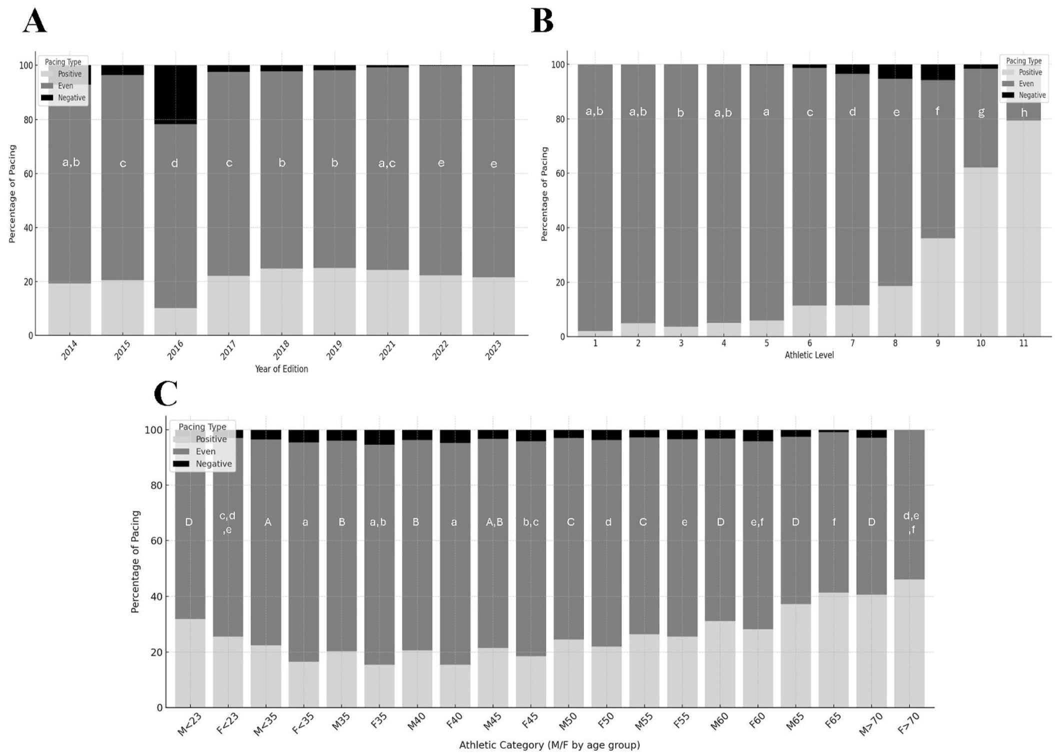

FIGURE 2 | Evolution of the pace profile during the marathon according to the edition year, athletic level and athletic category. Different letters indicate significant differences ($p < 0.05$) between groups. Uppercase letters indicate significant differences between men categories, while lowercase letters denote significant differences between women categories.

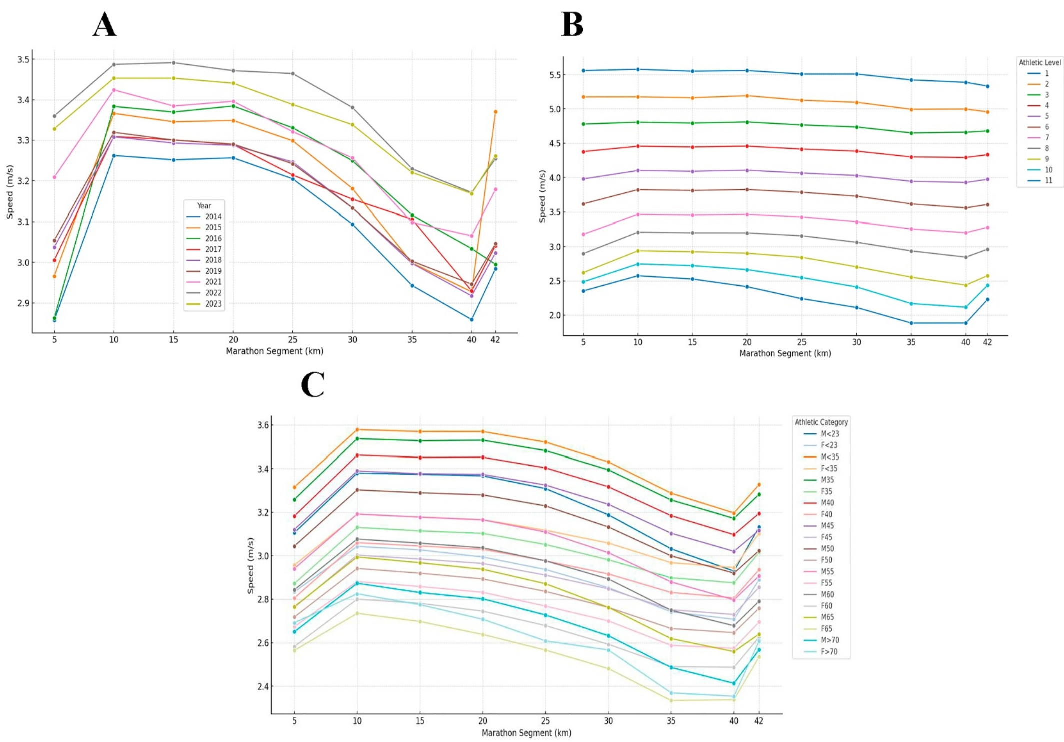

FIGURE 3 | Evolution of the velocity regarding year of marathon, athletic level and athletic category.

Similarly, when analysing relative speed (Supporting Information: Figure S1), a comparable profile is observed. However, it is important to highlight that, across all variables—sex, race edition, athletic level and category—the segment between kilometres 30 and 35 consistently represents the most critical point of performance decline.

Regarding the SSC (Supporting Information: Figure S2), the results confirm the previously mentioned profiles. The SSC profile reveals a clear structure: strong early acceleration, followed by a rapid drop in pace starting from the second segment (km15 vs. km10). Regardless of the year of edition, sex, athletic category or athletic level, the segment km10 versus km5 consistently emerges as the one with the highest SSC (%)—the point where runners accelerate the most. By contrast, the segment km35 to km30 is consistently the point of greatest slowdown—the lowest SSC (%), this segment corresponds to the well-documented 'marathon wall'.

Supporting Information: Figure S3 shows the coefficient of variation of running speed. In all samples, women displayed lower CV values than men (6.79 ± 5.14% vs. 7.40 ± 5.43%, $p < 0.001$, respectively). Moreover, there are significant differences ($p < 0.001$) between all editions except between 2022 and 2023, where the lowest CV values were recorded. Differences are also observed when comparing by athletic category ($p < 0.001$). In men, no significant differences are observed from the < 35-year category to M50; however, starting from M50, there is a significant increase in CV between categories up to > M70. In $M < 23$, CV values are similar ($p > 0.05$) to those in categories above M55. In women, significant change in CV begins from F40; the F60 and F65 categories show the highest CV values, with significant differences ($p < 0.01$) below F50, except for the $F < 23$ category, which reaches similar values. Taking the athletic level into account, it is from category 5 onwards that a significant ($p < 0.001$) increase in CV occurs.

With respect to HTW (Figure 4), women show a higher prevalence both at km 30 (women = 28.6% vs. men = 22.6%, $p < 0.001$) and at km 35 (women = 45.5% vs. men = 43.7%, $p < 0.001$). These differences are significant only between 35 to 55 age categories. Athletic category has a strong impact on the prevalence of the HTW. The extremes of the spectrum (young, inexperienced and veteran athletes) tend to show higher HTW, whereas athletes in the 24–45 age range show the lowest prevalence at both kilometre points and in both sexes. In terms of the year of the marathon edition, a significant reduction ($p < 0.001$) in the percentage of HTW at both distance markers is observed starting in 2021. Lastly, the percentage of athletes who experience HTW in both distances increases significantly starting from level 5, with an exponential trend in its prevalence emerging from that point onward. The logistic regression analysis revealed that SSC across specific marathon segments are strong predictors of HTW. For the HTW at kilometre 30, the most influential segments were SSC km 20 versus Km 15 and SSC km 15 versus Km 10 with odds ratios (ORs) of 0.019 (95% CI: [0.016, 0.021]) and 0.063 (95% CI: [0.058, 0.069]), respectively. For the HTW at kilometre 35, the same segments exerted significant effects, with ORs of 0.318 (95% CI: [0.312, 0.324]) for SSC km 20 versus Km 15 and 0.444 (95% CI: [0.438, 0.451]) SSC km 15 versus Km 10. These findings underscore that controlled deceleration between kilometres 15 and 30 serves as a physiological buffer against extreme fatigue, highlighting the critical importance of maintaining a steady pacing strategy throughout the mid-phase of the marathon. The inclusion of demographic and contextual variables in the logistic regression models

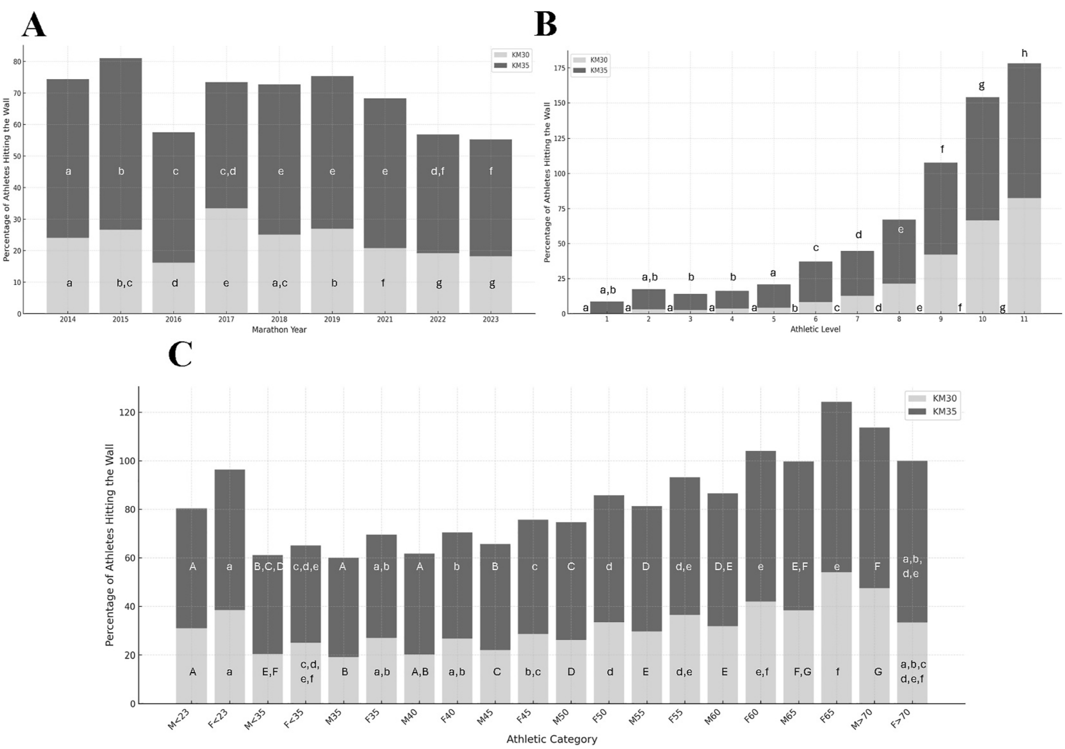

FIGURE 4 | The evolution of hitting the wall regarding marathon editions, athletic level and athletic category. Different letters indicate significant differences ($p < 0.05$) between years, athletic level and athletic category. Uppercase letters indicate significant differences between men categories, while lowercase letters denote significant differences between women categories.

revealed for the HTW at kilometre 30, that lower athletic level was the strongest predictor, with an ORs of 2.21 (95% CI: [2.18, 2.23], $p < 0.001$). Sex also showed a substantial effect, with females having ORs = 1.61 (95% CI: [1.55, 1.67], $p < 0.001$). For the HTW at kilometre 35, the patterns were similar. The athletic level remained the most influential factor, with an ORs of 1.79 (95% CI: [1.77, 1.80], $p < 0.001$), and female sex had a smaller but significant association (ORs = 1.10, 95% CI: [1.06, 1.13], $p < 0.001$).

By analysing the association between different variables, we found a significant correlation between marathon time and the CV of speed ($r = 0.551$ and $p < 0.001$) as well as with speed at 20 km, 25 km and 30 km ($r = -0.941$, $r = -0.951$ and $r = -0.929$, respectively; $p < 0.001$). Additionally, marathon time was correlated with a relative speed at 10 km ($r = 0.478$ and $p < 0.001$), 15 km ($r = 0.467$ and $p < 0.001$), 20 km ($r = 0.354$ and $p < 0.001$), 35 km ($r = -0.344$ and $p < 0.001$) and 40 km ($r = -0.385$ and $p < 0.001$) as well as with SSC between km 10 and km 5 ($r = 0.330$ and $p < 0.001$).

Moreover, runners with EP show a significantly lower CV, HTW much less frequently at both kilometre 30 ($p < 0.001$) and 35 ($p < 0.001$) and require less end spurt ($p < 0.001$). After adjusting for athlete profile variables (level, sex and athletic category), it is clear that the EP strategy is the most effective approach, leading to an average improvement of 27–34 min ($p < 0.001$) over positive and negative pacing, respectively. Moreover, those who HTW, especially at km 30, perform significantly worse, with longer marathon times ($p < 0.001$) and greater pacing variability; runners who experience "the wall" at kilometre 30 take, on average, 36 min and 18 s longer to finish the marathon compared to those who do not. Similarly, those who hit the wall at kilometre 35 finish 27 min and 58 s slower on average than those who avoid it. These time differences highlight the substantial impact of HTW on overall marathon performance. Finally, athletes who resort to an end spurt tend to have poorer overall marathon performance ($p < 0.001$).

4 | Discussion

The main objective of this study was to analyse the evolution of pacing over the last 10 years in the Trinidad Alfonso EDP Valencia Marathon in relation to sex, age and athletic level. The main findings of this study were as follows: (1) Taking into account the absolute speed, relative speed and SSC, a structural characteristic of marathon performance behaviour—regardless of the different variables analysed—reveals a clear pattern: a strong early acceleration followed by a rapid drop in pace starting from the second segment between kilometres 10 and 15. (2) An EP is significantly associated with marathon performance, in part because this pacing approach is linked to a lower occurrence of HTW. (3) Overall, participants adopted an EP strategy and displayed an end spurt. (4) The edition year, sex, category and athletic level influence marathon performance and pacing profile: 20.1–2023 editions, faster runners and younger athletes showed a higher percentage of EP, a lower CV and percentage of HTW. (5) The speed, CV of speed and SSC in certain marathon segments are significantly associated with the final marathon time, with km 10 and km 40 standing out as key points, being the fastest and slowest, respectively. Furthermore, faster speeds in the km 20–km 30 zone are highly predictive of better marathon outcomes.

Because the intentional distribution of speed, power and energy, referred to as 'pace' or 'pacing strategy', is recognised as a key determinant of optimal running performance (Pryor et al. 2020), these findings highlight the importance of pace control, as a motor control skill, in marathon performance. EP throughout the course lead to significant differences in final performance. Faster speeds in the km 20–km 30 zone are highly predictive of better marathon outcomes. This segment likely reflects both an athlete's pacing discipline in the early part and their endurance heading into the most fatiguing phase of the race. Furthermore, experiencing the HRW, whether at km 30 or km 35, significantly increases final race time. Early overexertion (high relative speed between km 10–20) is the strongest predictor of HTW. Therefore, HTW is a multifactorial phenomenon related to pacing strategy, training status and physiological variables, such as glycogen availability, and remains a cross-cutting challenge, affecting runners across all levels and ages. Moreover, a low CV is a marker of good pacing, associated with a lower risk of HTW and better overall performance.

Due to the different orographic and environmental circumstances in which different marathons are held, it is difficult to make a comparison between the current study and previous ones. However, these results are consistent with those of other studies and suggest an effect of sex, age and performance on pacing (March et al. 2011; Nikolaidis and Knechtle 2018a; Trubee 2011). However, and in agreement with Nikolaidis and Knechtle (2017), the age × performance level interaction effect on pacing, that is, whether runners with similar race times but at different ages present different variations of running speed during a marathon race, was not analysed. In general, and in agreement with Muñoz-Pérez et al. (2020), a predominance of EP was found for both men and women, regardless of their performance differences, in athletes finishing under 3h 30 min; although in the current study, faster race speeds were related to more EP, which was in agreement with previous studies (March et al. 2011; Nikolaidis and Knechtle 2017). Especially in the current study, athletic level 5 (< 3 h for men and < 3 h 15' for women) could represent a critical threshold, where pacing strategy begins to deteriorate significantly, likely associated with lower training levels, experience or physiological capacity.

As expected, running speed was higher in men than in women for the same performance level and category and in all splits. Therefore, in line with Deaner et al. (2015), the sex difference in pacing is strong and it may indicate sex differences in physiology, decision-making or both. Additionally, and according to Santos-Lozano et al. (2014), although women show lower CV values than men, they display higher percentages of end spurt and HTW. Overall, pace profile appears to depend less on sex than on the performance level or athletic category. The findings do not support previous research showing a lower percentage of HTW in women (Smyth 2021).

On the other hand, in line with previous studies (Nikolaidis and Knechtle 2017; Ristanović et al. 2023), the best and youngest runners show an end spurt and HTW less frequently as well as a lower CV in speed than other athletes. The missing end spurt in high-performance runners can be explained by a better energy distribution (Ristanović et al. 2023), which may be due to the fact that the elite athletes are aiming to preserve their position in the race, whereas amateur runners, whose intentions are rather to finish the race in the shortest possible time or improve their personal best, would try to 'sprint' in the last part of the race (Santos-Lozano et al. 2014). Additionally, and according to Cuk et al. (2019), it is also noteworthy that young athletes, < 23 years, regardless of sex, show CV values, HTW and a marathon pacing profile such as older athletes. A possible explanation for this might be that since pacing is influenced by an interaction between feedback and prior experience (Micklewright et al. 2010), the ability to perceive and control running speed may be a learnt pattern following extensive training and competition experience. In this regard, novice runners may not possess as well-developed metacognitive skills as more experienced elite runners, indicating that runners' metacognitive skills and attentional strategies develop as they gain more experience (Brick et al. 2018). Indeed, the best runners may have more experience and deliberate practice and know themselves better than less experienced athletes. Similarly, temporal and spatial perception can be seen as a cognitive skill of endurance runners, with higher-level athletes exhibiting better perceptual performance than lower-level runners (Latorre-Román et al. 2020). In addition, it is interesting to note that no differences exist in pacing among elite (< 2 h: 10) and well-trained (< 3 h: 00) marathoners, which means they displayed similar race profiles despite their performance The findings of the present study are only consistent with the men of the 2017 Berlin Marathon (Muñoz-Pérez et al. 2020).

In the current study, the CV of speed is significantly and positively correlated with the final marathon time. The CV of speed in men and women found in the present study is similar to that of the study by Santos-Lozano et al. (2014) conducted at the New York Marathon (men = 7.40 vs. 7.8% and women = 6.79% vs. 6.6%), respectively. The higher CV values in speed found in men from the < 35-year category up to the 55-year category could be due to men overestimating their marathon capabilities (Hubble and Zhao 2016). However, unlike the current study, a study conducted at the Athens Classic Marathon did not find significant differences in the CV of speed between sexes and age groups (Nikolaidis and Knechtle 2018b).

With regard to the year of the race, it is noteworthy that 2021, 2022 and 2023 had the best overall marathon times, with the highest percentages of athletes displaying EP and the lowest CV values in speed. Additionally, these editions showed the lowest percentages of athletes experiencing HTW. Although we do not have data on the use of carbon-plated shoes in these editions, their use has increased among elite and amateur runners in Spain since they entered the market in 2020. Several studies demonstrate performance improvements, particularly in marathons, with the use of these shoes, especially due to their ability to decrease the energetic cost of running (Rodrigo-Carranza et al. 2021). Because running at a constant speed is the most metabolically efficient pacing strategy for completing an endurance race in a given time (Rapoport 2010), a better pacing strategy could provide elite marathon runners with an economical pathway to significant performance improvements at the world-record level (Angus 2014). Indeed, every woman's and man's world record from 5 km to the marathon has been broken since the introduction of carbon-fibre plate shoes in 2016 (Muniz-Pardos et al. 2021). Specifically, a retrospective analysis of 99 world-class male marathon runners' performances between 2012 and 2021 showed a 1% improvement in world-class male marathon running speed when running with this type of shoe (Langley and Langley 2024). Future studies could verify the precise association between the use of this type of shoe and pacing control strategies during the race.

This study should be considered with the following limitations. First of all, the lack of additional information on other factors that could affect marathon pacing, such as the exact age of the athletes, their previous experience, anthropometric and fitness characteristics and prior injuries. Secondly, it was not possible to analyse the effect of group running on pace control. Thirdly, the length of each segment, measured every 5 km except for the 42.2 km segment, could affect variability results; data collected every km might be more precise. Fourthly, the year 2016 shows anomalous behaviour, and its comparison with previous and subsequent years reveals highly significant changes, which could be attributed to weather-related factors, alterations in the marathon course layout, technological failures, logistical challenges or poor supply management. Finally, caution should be taken when generalising these findings to other marathons, especially those with significant elevation changes or high levels of thermal stress that could affect physical and mental effort. Nevertheless, this study had several strengths. First, to the best of our knowledge, this was the first study to investigate these aspects of pacing in a Spanish marathon. Additionally, this study incorporates the analysis of a wide range of diverse variables that influence pace control, which have not been analysed in this way in previous studies. Although definitive conclusions cannot be established, the temporal comparison of the analysis conducted from 2014 to 2023—when many athletes wearing carbon-plated shoes appeared in the race during recent editions—adds scientific value to this study.

5 | Conclusions

In summary, the results of this study confirmed the effect of sex, age and athletic level on pacing strategy. Overall, participants adopted an EP strategy and displayed an end spurt. The edition year, sex, category and athletic level influence marathon performance and pacing profile: in the 2022 and 2023 editions, faster runners and younger athletes showed a higher percentage of EP, a lower CV and a lower percentage of HTW. Moreover, the 2022 and 2023 editions showed the best overall marathon times. EP, CV, speed itself and its cost in certain marathon segments are significantly associated with final marathon time. These findings highlight the importance of pace control, as a motor control skill, in marathon performance. Differences by level, age and sex should be taken into account when planning training. Specific training at steady paces and the use of pacing technology (GPS watches, pace planners) could significantly improve performance.

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Ethics Statement

The present research does not involve human or animal research.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

All the data are available in the manuscript or in the supplementary files.

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Supporting Information

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