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Review

Pacing profiles and tactical behaviors of elite runners

Running head: *Pacing in elite distance runners*

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Highlights:

- Elite athletes' pacing behaviors differ depending on race distance and whether races longer than 800 m are conducted during championships or "meets".
- Optimizing finishing position requires the adoption of a leading position with as much as a lap remaining in 1500 m and 5000 m championship races.
- Staying within a pack of runners who follow a realistic, non-excessive pace from the beginning of major championship long-distance races is also recommended to optimize performance (finishing time).

Abstract

The pacing behaviors used by elite athletes differ among individual sports, necessitating the study of sport-specific pacing profiles. Additionally, pacing behaviors adopted by elite runners differ depending on race distance. An "all-out" strategy, characterized by initial rapid

acceleration and reduction in speed in the later stages, is observed during 100 m and 200 m events; 400 m runners also display positive pacing patterns, which is characterized by a reduction in speed throughout the race. Similarly, 800 m runners typically adopt a positive pacing strategy during paced "meet" races. However, during championship races, depending on the tactical approaches used by dominant athletes, pacing can be either positive or negative (characterized by an increase in speed throughout). A U-shaped pacing strategy (characterized by a faster start and end than during the middle part of the race) is evident during world record performances at meet races in 1500 m, mile, 5000 m and 10,000 m events. Although a parabolic J-shaped pacing profile (in which the start is faster than the middle part of the race but is slower than the endspurt) can be observed during championship 1500 m races, a negative pacing strategy with microvariations of pace is adopted by 5000 m and 10,000 m runners in championship races. Major cross country and marathon championship races are characterized by a positive pacing strategy; whereas a U-shaped pacing strategy, which is the result of a fast endspurt, is adopted by 3000 m steeplechasers and half marathoners. In contrast, recent world record marathon performances have been characterized by even pacing, which emphasizes the differences between championship and meet races at distances longer than 800 m. Studies reviewed suggest further recommendations for athletes. 800 m runners should avoid running wide on the bends throughout the whole race. In turn, during major championship events, 1500 m, 5000 m, and 10,000 m runners should try to run close to the inside of the track as much as possible during the decisive stages of the race when the speed is high. Staying within the leading positions during the last lap is recommended to optimize finishing position during 1500 m and 5000 m major championship races. Athletes with more modest aims than winning a medal at major championships are advised to adopt a realistic pace during the initial stages of long-distance races and stay within a pack of runners. Coaches of elite athletes should take into account the observed difference in pacing profiles adopted in meet races *vs.* those used in championship races: fast times achieved during races with the help of one or more pacemakers are not necessarily replicated in winner-takes-all championship races, where pace varies substantially. Although existing studies examining pacing characteristics in elite runners

through an observational approach provide highly ecologically valid performance data, they provide little information regarding the underpinning mechanisms that explain the behaviors shown. Therefore, further research is needed in order to make a meaningful impact on the discipline. Researchers should design and conduct interventions that enable athletes to carefully choose strategies that are not influenced by poor decisions made by other competitors, allowing these athletes to develop more optimal and successful behaviors.

Keywords: Athletics; Distance running; Pacing; Sprinting

1. Introduction

Pacing is the term used to describe the distribution of muscular work throughout an exercise bout. It is considered to be a fundamental requirement of successful endurance performance[1] and is reliant on continuous decision-making processes.[2] Strategic decisions regarding the overall approach to the event are made beforehand, whereas tactical decisions during the event respond to changes in physiological status and the behavior of rivals.[3] Pacing behaviors differ according to the mode of exercise, the event's duration, the knowledge and experience of the athlete and each opponent's physiological capacity.[4] Several pacing profiles were described in 2008 by Abbiss and Laursen,[5] including a negative profile (an increase in speed over the duration of the event), a positive profile (a decrease in speed over the duration of the event), an "all-out" profile (characterized by initial rapid acceleration and reduction in speed in the later stages), an even profile, a parabolic-shaped profile (including U-shaped, reverse J-shaped and J-shaped) and variable pacing.

These profiles were originally based on analyses that predominantly focused on swimming, cycling and rowing.[5] Not surprisingly, research on running was largely absent, given that sufficient high-resolution, official performance data from global championship track races (e.g., 800 m, 1500 m, 5000 m, and 10,000 m) were rarely available for analysis until 2008. Given the differences, such as aerodynamic drag, that exist between running and other individual sports like cycling and speed skating, there is a very strong rationale for updating the current understanding of pacing in running. Building on the excellent foundation laid by Abbiss and Laursen,[5] pacing profiles in running can now be established. The requirements for runners vary depending on the distance being run: middle-distance runners require a greater aerobic contribution than sprinters; long-distance runners face different challenges depending on whether they are competing on a track, on a road, or in cross country; and championship races emphasize winner-takes-all competitions in which the main goal is to either qualify to following rounds during heats and semifinals or to achieve either a finalist or a medalist position during the final race that contrast with regular meets, such as Diamond League events or big-city marathons, that employ pre-arranged pacemakers who set a specific pace from the beginning to help runners achieve the fastest possible finishing times. In addition, meet races do not involve preliminary rounds such as heats and semifinals and final races as championships do. These differences that exist among running events makes them an invaluable source for furthering our understanding of the pacing behaviors used by successful and unsuccessful athletes, by men and women and by runners within different competition formats. Such information can provide coaches and athletes with real-world insights into improving performance. Since the time that Abbiss and Laursen[5] published their early review of pacing research, an extensive body of new literature on pacing in running has been produced. In this paper, we examine the literature relating to elite running events. Furthermore, we explore differences between theoretically optimal pacing strategies and the behaviors that result from tactical decisions during championship racing, where the primary goal is to achieve a high finishing position rather than a fast time. In our review, the figures produced to illustrate pacing strategies are original and are based on the open-access data reported in the cited literature.

2. 100 m and 200 m

In short events, athletes adopt an “all-out” strategy,[5] as evidenced by the fact that 100 m and 200 m sprinters competing at the International Association of Athletics Federations (IAAF) World Championships achieved maximal speeds in the early stages followed by a progressive slowing until the finish line,[6–9] although the 200 m is usually run with a faster second half overall[10,11] (Fig. 1A–D). This pacing strategy is likely a product of the high energetic cost of acceleration. Achievement of a high initial speed in a sprint allows minimization of total energy cost, even if there is a progressive loss of speed.[5] It has been found that the acceleration phase required to achieve peak speed in the 100 m race covers 50%–60% of the total distance[6,7] and therefore it has been calculated that 20%–25% of the overall work performed is required to accelerate the body from the static starting position.[5] The all-out nature of these races suggests a minimal impact of strategic or tactical considerations on behaviors displayed in either championship or non-championship type races, which thus do not differ in speed profiles.

3. **400 m**

In contrast to the 100 m and 200 m events, observations made during 2 separate IAAF World Championships[6,12,13] suggest that truly maximal velocity is not achieved during 400 m races. Rather, the pace for 400 m is characterized by high, but not maximal, starting speeds and progressive deceleration, resulting in an overall positive profile[12,13] (Fig. 1E and F). As an illustration, Wayde Van Niekerk, the 2017 men's 400 m World Champion, recorded a split time of 10.69 s for the first 100 m in the final,[12] whereas in the same championships he recorded a split time of 10.15 s for the first 100 m during his silver medal run in the shorter 200 m final.[10]

In addition to the mechanical explanations for observed pacing behaviors in 400 m races, there are physiological mechanisms that partially account for them as well. Short and high-intensity exercise causes rapid depletion of intermuscular high-energy phosphates resulting in impairment of muscle contractility and force production. Nummela et al.[14] suggested that the gradual reduction in speed throughout most of the 400 m event was evidenced by a reduction in the ability of the muscles to generate force (i.e., peripheral physiological fatigue) despite a gradual increase in motor unit activation (measured using electromyography).

An important characteristic of the 100 m, 200 m, and 400 m sprint events is that athletes complete the entire distance in their own individually allocated lanes. This suggests that pacing behaviors during these sprint events are less strategic in nature than in longer events, where competitors are able to share the inside lane and can vary tactical behaviors related to minimization of distance covered[15] or energetic benefits gained by drafting behind other runners. However, due to the absence of these benefits in the sprints, pacing behavior in the shorter events should differ little between major championship races and meet races. Rather, any differences between these types of competitions could be related to the athlete's ability to recover from preliminary races, since major championships involve heats, semi-finals and a final within, at most, a 4-day period.[8,9] It is plausible that higher-performing athletes recover faster than athletes with less ability, whose performances are good enough to qualify for successive rounds during championships, but are at a higher speed relative to their season's best (SB) times than better athletes. In 2016, for example, 2 days before breaking the men's 400 m world and Olympic records in a time of 43.03 s, Wayde Van Niekerk (mentioned above) ran his 400 m heat in 45.26 s, more than 2 s slower than his record-setting time (data obtained from the open-access website www.worldathletics.org). Therefore, it is very likely that his 400 m heat did not require a considerable effort from him, especially when compared with the fatigue that his less-able rivals possibly felt.

4. 800 m

The 800 m is a middle-distance running event typically characterized by a positive pacing strategy similar to that displayed in 400 m running.[13,14] In contrast to the sprints, athletes in races of 800 m and longer are not confined to their own lanes (except for the first bend in the 800 m). This means that athletes must consider in their pacing strategies how running wide on the bends increases the total distance covered. Indeed, during the men's final at the Olympic Games in 2000, the eventual silver medalist had a faster mean speed than the winner, but lost because he ran a greater total distance through poor tactical and positional decision making.[15] Tucker et al.[16] analyzed lap times from 26 world record performances in the 800 m distance from 1912 to 1997 and found that the second lap of the race was consistently slower; indeed, on only two occasions was the second lap faster. Similarly, Sandford et al.[17] found that runners ran the first lap faster than the second lap in the 2012 Olympic 800 m final, in which the Kenyan runner David Rudisha established the current men's world record. de Koning et al.[18] also reported that positive pacing strategies were typically displayed in 800 m major championship races. These observations on pacing strategies for 800 m races are similar to those previously described for 400 m events, despite substantial differences in absolute speed and metabolic demands.[19] This positive pacing strategy has previously been explained as the need to accelerate rapidly in the early stages of the race to achieve at least the fatigue-threshold running speed as quickly as possible. It has been proposed that this fatigue-threshold running speed is the highest speed that can be maintained throughout any entire event according to the body's physiological limitations, such as pulmonary gas exchange, blood acid-base status and blood lactate concentration.[20] Tucker et al.[16] suggested that, in the 800 m event, the speed set by world-class athletes during the early stages of races was even higher than the fatigue-threshold velocity, and therefore the positive pacing strategy observed concurs with the existence of a metabolic limit on the ability to compensate for lost time later in the race.

Filipas et al.[21] analyzed the pacing behavior of 142 800 m SB performances of world-class athletes in meet races and found sex-based differences in pacing. Although the first 200 m split time was always faster than any other 200 m segment, in the men's races the last three 200 m split times were progressively slower, whereas in women's races the remaining 200 m split times did not differ. Consequently, it has been suggested that the relatively slower second 200-m segment for women is caused by the relatively lower performance standard in women's competition.[21] This could mean that female 800 m runners are not required to maintain a very fast initial pace during the second 200-m segment to retain their race position in the same way that men are.[21] However, these pacing strategies are not always followed during major championship races, where the primary goal is to achieve a high finishing position and not necessarily a fast time. It is also possible that the strategic and tactical pacing behaviors displayed in championship races are influenced by the behaviors of the dominant athletes at that time. Sandford et al.[17] has described two different time eras in recent global championships (Olympic Games and IAAF World Championships): 2005–2009 and 2011–2016. In the latter era, and because of the dominance of the front-running David Rudisha, the pacing strategies adopted during the finals were positive, with a faster first lap. However, in the former era, championship races were characterized by negative splits with a faster second lap.[17] Therefore, an athlete's pacing strategy in a race is influenced by the behavior of opponents,[3] whereas a dominant athlete can decide to start quickly and adopt a positive pacing profile. In the case of David Rudisha, who won the 2012 Olympic final in a world record time, it is possible that his strategy was to run fast from the beginning, knowing that it would result in an overall positive pacing profile but would be unsustainable for his rivals, whose strategy was most likely to follow Rudisha for as long as possible. That six of his seven rivals in that race recorded personal best (PB) times is a testament to performances made possible by simply following a dominant front-runner, and unintentionally showed the value of having an excellent pacemaker. Thus, present-era runners might face specific circumstances similar to those described in the pacing strategies used during former 800 m world record perfomances,[16] in which runners overcame the fatigue-threshold speed early during the first lap, thereby achieving faster overall performances, like those achieved during Rudisha's world record performance. However, runners in the former era did not even reach the fatigue-threshold speed during the first lap, and further displayed an inability to make up lost time during the second half.[20]

Few 800 m races follow the pattern set in the men's 2012 Olympic final. However, the positive pacing strategy observed in most world-class 800 m races[14,15,18,19] was also observed during the qualifying heats and semi-finals of the 2017 IAAF World Championships,[22] suggesting that pacing behavior is not primarily influenced by different competitive goals (i.e., qualification for the next round of a championship either directly or as a "fastest loser" (those athletes who ran the fastest times out of all those who did not earn an automatic qualifying spot in a heat or semifinal and qualified for the next round), or attempting to achieve the fastest possible time during a non-championship race). Furthermore, Hanley and Hettinga[23] highlighted the need for runners to optimize their tactical approach during major championships because the differences in the finishing times between qualifiers and non-qualifiers to the next round, or between medalists and non-medalists, are extremely small. Men and women competing in 800 m races at

Hettinga et al. (2019)[35]	5000 m	OG, WC (F)	Men and women	Negative
Aragón et al. (2016)[31]	5000 m	OG, WC, EC (F)	Men	Negative
Thiel et al. (2012)[24b]	5000 m	WR, WC	Men and women	Even and negative.
Tucker et al. (2006)[16]	10,000 m	WR	Men	Even with endspurt
Filipas et al. (2018)[34]	10,000 m	OG, WC (F)	Men and women	Even with endspurt
Hettinga et al. (2019)[35]	10,000 m	OG, WC (F)	Men and women	Even with endspurt
Thiel et al. (2012)[24b]	10,000 m	WR, WC	Men and women	Even and negative
Hanley (2014)[43]	Cross country	WC	Men	Positive
Esteve-Lanao et al. (2014)[44]	Cross country	WC	Men	Positive
Hanley (2018)[46]	Cross country	WC	Men and women	U-shaped
Hanley (2015)[49]	Half marathon	WC	Men and women	Even with endspurt
Hanley (2016)[48]	Marathon	OG, WC	Men and women	Positive
Hettinga et al. (2019)[35]	Marathon	OG, WC	Men and women	Positive
Renfree et al. (2013)[50]	Marathon	WC	Women	Positive
Angus (2014)[51]	Marathon	WR	Men	U-shaped and varied
Díaz et al. (2019)[52]	Marathon	World Majors	Men	Different among courses
Díaz et al. (2018)[53]	Marathon	WR	Men	Positive and negative
Díaz et al. (2019)[58]	Marathon	WR	Men and women	Negative and even
Billat et al. (2020)[59]	Marathon	WR	Men and women	Negative and even

[a] Pacing strategies are indicated for 100 m, 200 m, and 400 m performances in the order listed.

[b] Pacing strategies are indicated for world record performances and for Olympic Games performances in the order listed.

Abbreviations: EC = European Championships performances; F = only final race; OG = Olympic Games performances; Q = only qualification races; WC = World Championships performances; WR = world record performances.

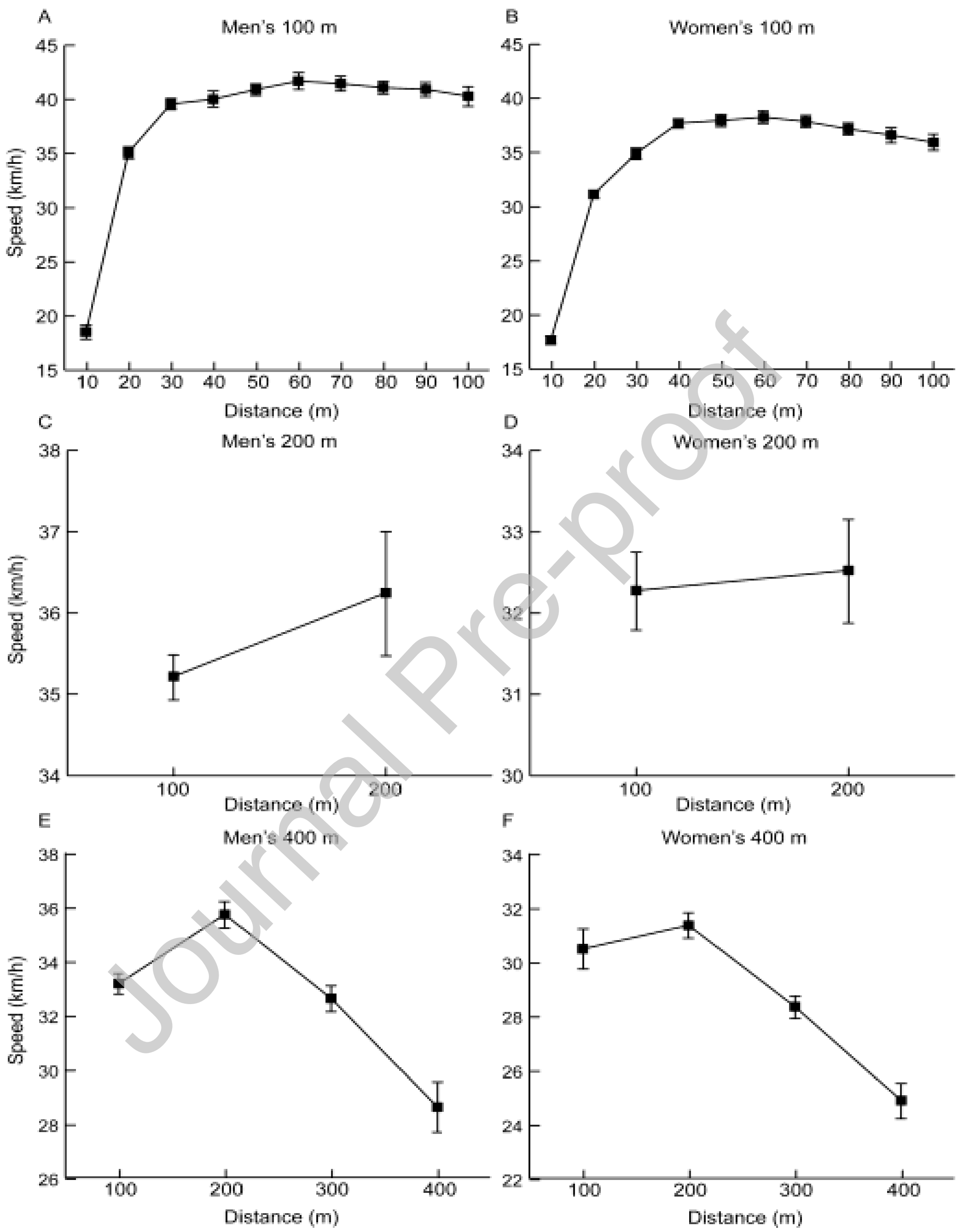

Fig. 1. The 10 m segment speeds for the men's and women's 100 m finals (A and B) and the 100 m segment speeds for the men's and women's 200 and 400 m finals (C–F) at the 2017 IAAF World Championships. Data were obtained from the open-access World Athletics website (worldathletics.org). Data were presented as mean ° SD.

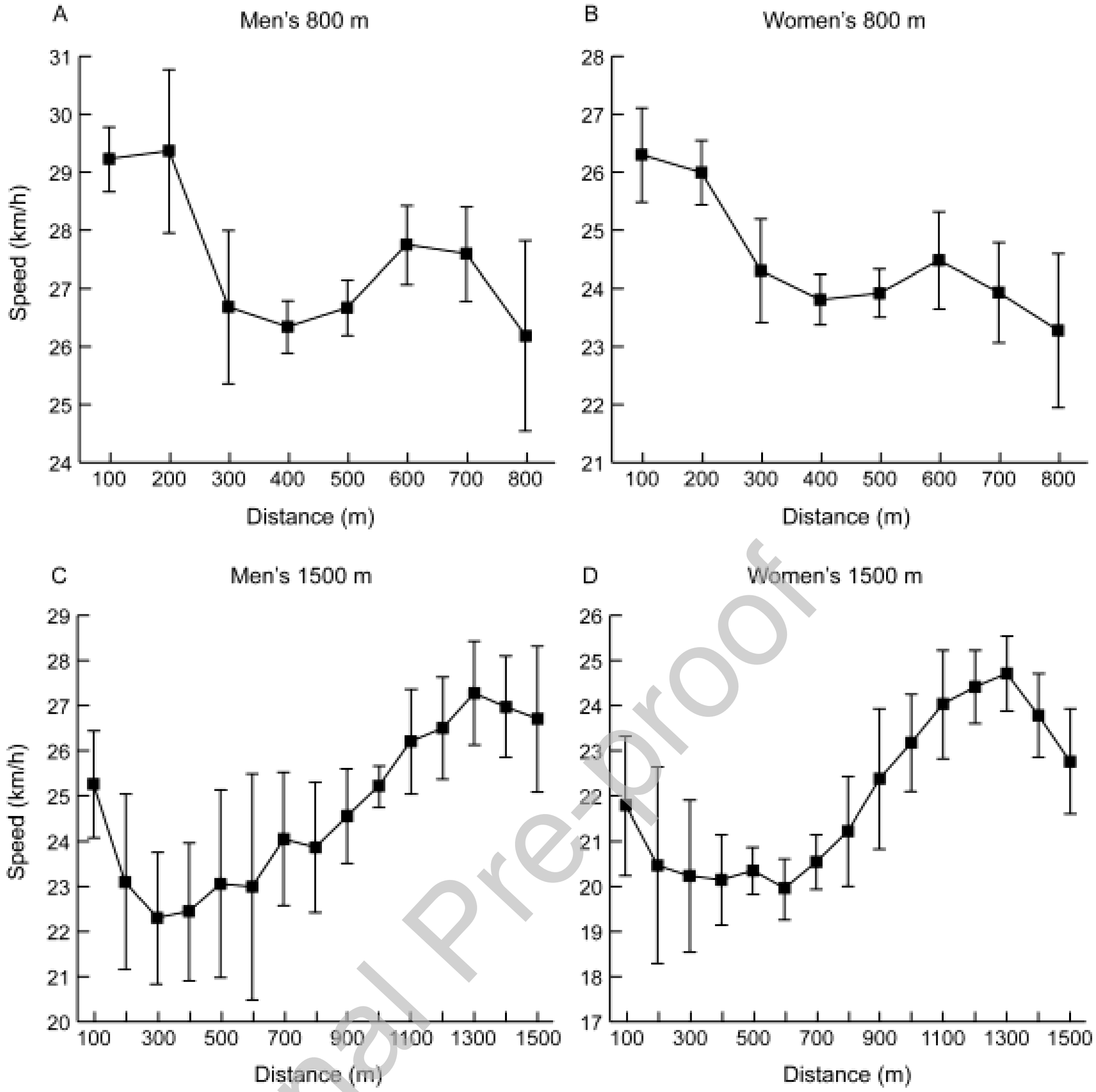

Fig. 2. The 100 m segment speeds for the men's and women's 800 m (A and B) and 1500 m (C and D) finals at the 2008 Olympic Games and 2013 and 2017 IAAF World Championships; data for the 1500 m obtained from the 2016 Olympic Games are also included. Data were obtained from the open-access World Athletics website (worldathletics.org). Data were presented as mean ° SD.

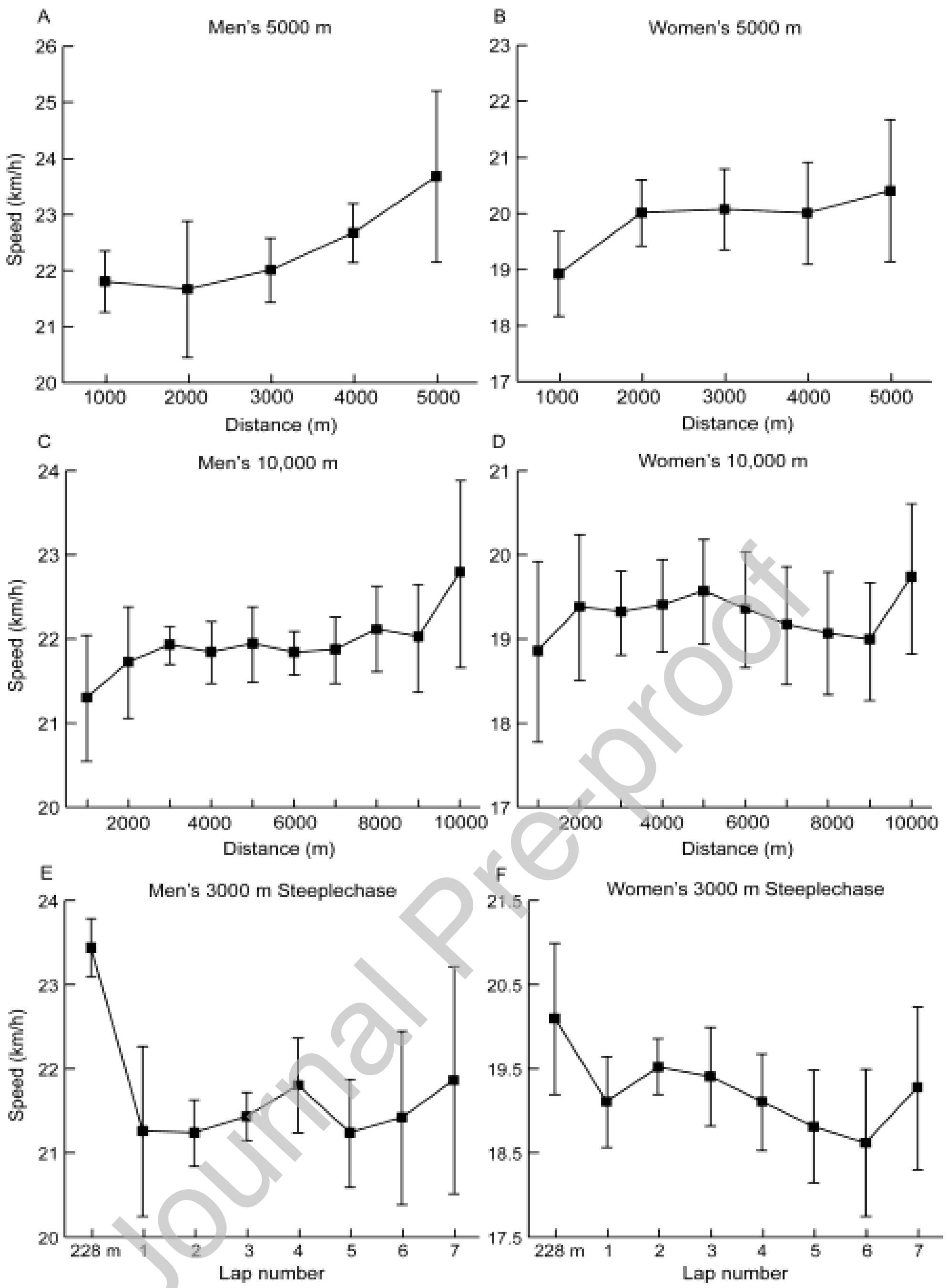

Fig. 3. The 1000 m segment speeds for the men's and women's 5000 m and 10,000 m finals at the 2008 and 2016 Olympic Games and 2013 and 2017 IAAF World Championships (A–D) and the first 287 m segment speeds and speeds for the remaining 7 laps for the men's and women's 3000 m steeplechase finals at the 2008 and 2016 Olympic Games (E and F). Data were obtained from the open-access World Athletics website (worldathletics.org). Data were presented as mean ° SD.

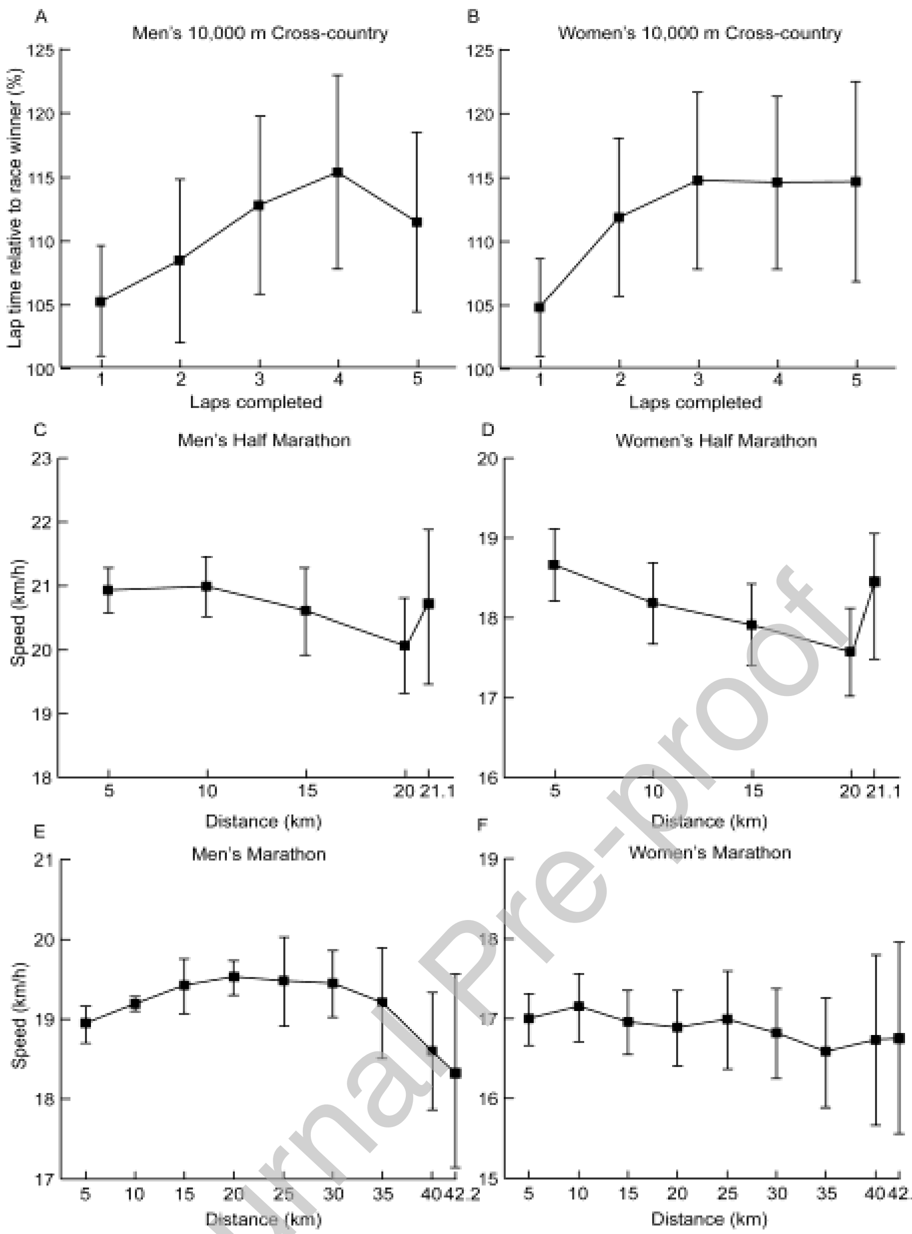

Fig. 4. The 2 km segment speeds for the men's and women's 2017 IAAF World Cross Country Championships (A and B), the 5 km segment speeds and final 1.1 km segment speeds for the men's and women's half-marathon races at six IAAF World Championships from 2007 to 2014 (C and D), and the 5 km segment speeds and final 2.2 km segment speeds for the men's and women's marathon races at the 2016 Olympic Games and 2013 and 2017 IAAF World Championships (E and F). Data were obtained from the open-access World Athletics website (worldathletics.org). Data were presented as mean ° SD.

Graphical abstract