Velocity and Stride Parameters of World-Class 400-Meter Athletes Compared With Less Experienced Runners

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Abstract

Hanon, C and Gajer, B. Velocity and stride parameters of world-class 400-meter athletes compared with less experienced runners. *J Strength Cond Res* 23(2): 524–531, 2009—The purpose of this study was to determine, based on the time course of the velocity and stride pattern recorded in each 50-m segment of a 400-m competition, whether elite 400-m runners present the same pacing strategy as less successful athletes. Based on video data, 3 different levels of performance were analyzed: world-class, national, and regional levels for both sexes, with each of the 6 groups comprising 5 subjects. The peak velocity was reached by all athletes between the 50- and 100-m marks with mean values of 8.96 and 10.12 $m \cdot s^{-1}$ for the 5 best women and men, respectively. Peak frequencies were observed in the second and third 50-m segments; peak values were 3.99 ± 0.13 for the world-class women (WWC) and 4.12 ± 0.19 for the men (MWC). A stride length of 2.29 ± 0.04 was observed for the WWC and 2.53 ± 0.08 for the MWC. The better athletes were able to achieve higher absolute and relative velocities (97.6 ± 0.5 [MWC] and 96.3 ± 0.7% [WWC] of their best performance for 200 m) at the 200-m mark compared with the lower-level athletes. Furthermore, the fatigue index was calculated as 22.99, 14.43, and 13.91% for the world-class, national, and regional levels, respectively. In summary, world-class runners adopt a more aggressive pacing strategy and demonstrate greater fatigue than the less experienced runners; this might indicate a greater mental commitment and/or a better capacity to run under fatigue.

Key Words pacing strategy, competition, stride length, stride frequency, fatigue index

Introduction

Because small differences in performance generally determine a competition outcome, information concerning the best way to expend the limited energetic sources available is of considerable interest. However, given the obvious importance of pacing on performance, there are relatively few studies available on this topic. The 400-m run is one of the most demanding athletic events. In this event, which is intermediate between sprint and middle distance, a runner must be able to 1) reach a very high velocity using an economical technique and 2) be capable of preserving the optimal technical characteristics of stride despite intense fatigue. For these reasons, understanding the biomechanical factors in sprint running is critical to performance and is of interest to national coaches to identify areas for improvement to reach world-class levels.

International Athletic Amateur Federation (IAAF) analysis conducted during world championships has focused on time-course analysis of velocity with a precision of 100 m and, more recently, 50 m, but the available biomechanical data only allowed comparisons of the start and end of a 400-m run (1) or on the basis of 100 × 100-m divisions (2,20). Based on the 100 × 100-m analysis performed during world-level competition, the peak velocity measured during the 400-m run by Brüggeman and Glad (4) and the IAAF (13) was observed between 100 and 200 m, and peak values of 9.66 $m \cdot s^{-1}$ (men) and 8.62 $m \cdot s^{-1}$ (women) (Seoul 1988) and 9.63 $m \cdot s^{-1}$ (men) and 8.61 $m \cdot s^{-1}$ (women) were measured (13). In the last part of the race, a velocity decrease (between the peak velocity and the velocity measured in the last 100 m) was systematically observed and determined to be a 13–20% reduction.

To our knowledge, very few studies have been conducted to date with greater precision (50-m analysis). Sprague and Mann (22) only compared the beginning and the end of the race, demonstrating a peak velocity of 9.51 $m \cdot s^{-1}$ and a velocity decrease of 21%. The results collected by the IAAF during the Athens Olympic Games (5) revealed larger differences because the peak velocities were greater (10.03 and 8.97 for men and women, respectively) and were reached earlier in the race. Consequently, the calculated decrease in velocity was greater than 20%. The velocity, defined as the

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product of the stride length and the stride rate, is therefore the result of an optimal combination of these parameters. The available data show that the peak velocity was obtained with a frequency of 3.74 Hz and a length of 1.98 m for women completing the distance in 53.8 seconds (1) and 3.48 Hz and 2.28 m for men having covered the distance in 52.8 seconds (20). The velocity decrease was, therefore, the result of both a decrease in stride frequency and length. Nevertheless, the degree of precision obtained by these data does not allow an appreciation of the respective part of both of these parameters and their contributions to the velocity decreases of top-level athletes. Furthermore, to date, accurate data concerning good but less successful runners are not available. This comparative analysis would enable national coaches to determine the differences between their elite athletes to focus either on the first part (maximal velocity limit) or the latter part (fatigue resistance limit) of the race.

Therefore, the aim of the present study was to evaluate the time course of both the velocity and stride parameters (length and frequency) every 50 m during the 400-m events performed in competition to compare 3 different levels of performance to determine the expertise factors that discriminate world-class runners from their less experienced counterparts.

Methods

Experimental Approach to the Problem

To examine the effect of expertise on the pacing strategy of 400-m runners, the evolution of velocity and biomechanical parameters were studied. This comparison used data from 50-m segments of competition events from the start to the end of each race.

Subjects

Three different levels of performance were analyzed: world-class, national, and regional levels for both sexes. Each of the 6 groups had 5 subjects. The mean running time for each group was significantly different from every other group (Table 1). The training status of the subjects was 5–7 sessions a week for national standard and 3–5 times a week for regional level.

Procedures

The study was performed using 2 different video methodologies: one for the world-class level and the other for the national and regional levels.

Table 1. Average + *SD* of the performances.

	World-class level	National level	Regional level
Men	44.43 ± 0.16	46.83 ± 0.52	48.24 ± 0.31
Women	49.97 ± 0.33	53.06 ± 0.50	55.33 ± 0.30

Each group ($n = 5$) is homogeneous, and the 6 groups were statistically different, $p < 0.05$.

World-Class-Level Analysis

The analysis was performed using the IAAF pictures recorded during world championships. Nine video cameras operating at 50 Hz were placed perpendicular to the running direction for filming the runners when passing through markers that were placed every 50 m. Sequences were digitized to register the very moment at which each athlete passed the markers that had been filmed before. Mean stride number per segment was determined by visually counting the number of strides for each 50-m segment from the video document. If the final stride landed short or long of the 50-m line, a percentage of the stride was determined for that segment. This was done by taking into account the time at n (foot contact before the line) and the time at n + 1 (foot contact after the line) and then calculating a percentage. Example of calculation:

$$50 \text{ m} = 24 \text{ full strides, the 25th being on both sides of the line.}$$

Time at 24th contact: 30.75 seconds; time at 25th contact: 30.97; thus, the stride duration is 0.22 seconds.

Time at the line: 30.92 seconds (IAAF data).

Between the 24th step and the line: 0.17 seconds (30.92 − 30.75); that, is 77% [(0.22 / 0.17) × 100] of the stride duration. The following 23% was then considered in the next 50-m portion.

The total step numbers were then 24.77, and that value was used to calculate the mean stride length for that segment.

Mean stride frequency was calculated from the stride length and the velocities as follows: stride frequency = velocity / stride length.

National or Regional Analysis

The competition was an official meeting located at sea level in the northern hemisphere during the competitive season (end of June). This was a selective international event. The athletes signed an informed consent document before the investigation and answered questions regarding their best performance and morphologic data. The investigation was approved by an institutional review board for the use of human subjects.

The temperature was 22°, and the wind was inferior to 1.5 $m \cdot s^{-1}$. Before the competition, the track was marked every 50 m. On both sides of this line, additional marks were placed every 20 cm on 140 cm. The video system used consisted of 16 videotape recorders (Panasonic Super-VHS) with a double framework that allows one to obtain 50 frames per second and, thus, to decrease the error of measurement to 0.01 seconds for every 50 m. Three panoramic videotape recorders were placed in the stands (approximately 25 m from the track) to facilitate the determination of stride numbers for each 50-m segment.

These cameras observed corridors 1–3, 4–8, and 1–8 (help camera), respectively. The remaining 13 cameras were synchronized and were used to obtain the time for each 50-m segment. When no gap existed between the corridors (such as in the last 150 m), only 1 camera was necessary. However, when an important gap existed (such as in the first 250 m), 2 or 3 cameras were used.

The average stride length (distance / stride numbers) was then calculated on each 50-m part (margin of error: 2×5 cm). The exact stride lengths were calculated with the help of the additional marks on both sides of the lines.

Statistical Analyses

The effect of distance and the effect of expertise on velocity, stride rate, and stride length were determined by repeated-measures analysis of variance. The significance level was set at $p \leq 0.05$.

Results

The Velocity

The velocity was an average velocity for the considered 50-m part, calculated from times recorded for every 50 m.

As observed in Figure 1, the peak velocity was reached for all athletes between the 50- and 100-m marks. The velocities of the world-class group were significantly greater than the other levels during the first segment and remained greater until the 150- to 200-m segment in the women and until the 350- to 400-m segment in the men.

Three distinct periods in velocity were observed:

–An acceleration phase from the start until the end of the first bend (around 100 m and approximately 11–13 seconds)

–A progressive decrease of the velocity until 300 m

–A great decrease in velocity during the last 100 m

This final decrease in velocity was greatest for the world-class level, particularly in the women's group. Furthermore, the fatigue index (peak velocity − final velocity / peak velocity) × 100 was 22.99, 14.43, and 13.91% for the world-class, national, and regional levels, respectively.

Stride Length

As seen in Figure 2a, the peak values of stride length were 2.29 ± 0.04, 2.21 ± 0.07, and 2.16 ± 0.05 m, respectively, for women's world (WWC), national (WN), and regional (WR) runners and 2.53 ± 0.08, 2.40 ± 0.06, and 2.35 ± 0.08 m for men's world (MWC), national (MN), and regional (MR) runners, respectively (Figure 2b). This peak was observed at 100–150 m after the onset of the 400-m running except for the national-level runners, who reached their peak value one segment earlier. The stride length values of the world-class runners were significantly greater than those of the other runners, except for in the last segment (Figure 2, Table 2).

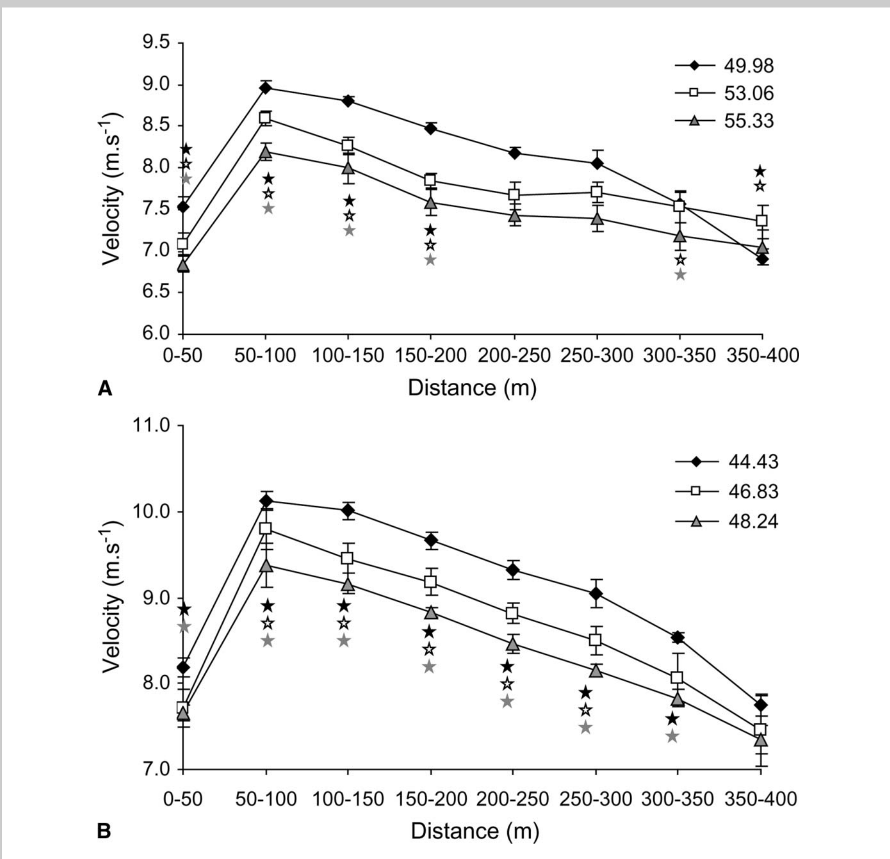

Figure 1. Time course of velocity for women (a) and men (b). For each group, $n = 5$. Black stars, gray stars, and white stars indicate that the difference is significant ($p < 0.05$) between world-class and national level, between world-class and regional level, and between national and regional level, respectively.

Step Frequency

Maximum step frequency was reached between 50 and 100 m when the velocity was maximal; peak step frequency was 3.99 ± 0.13, 3.89 ± 0.14, and 3.86 ± 0.16 Hz for the WWC, WN, and WR runners (Figure 3a). The final decrease in step rate was particularly important from 250 to 400 m in the WWC group and contrary to the WN and WR. Except for the last two 50-m runs, the differences were not significant between the groups of women runners. In the men's

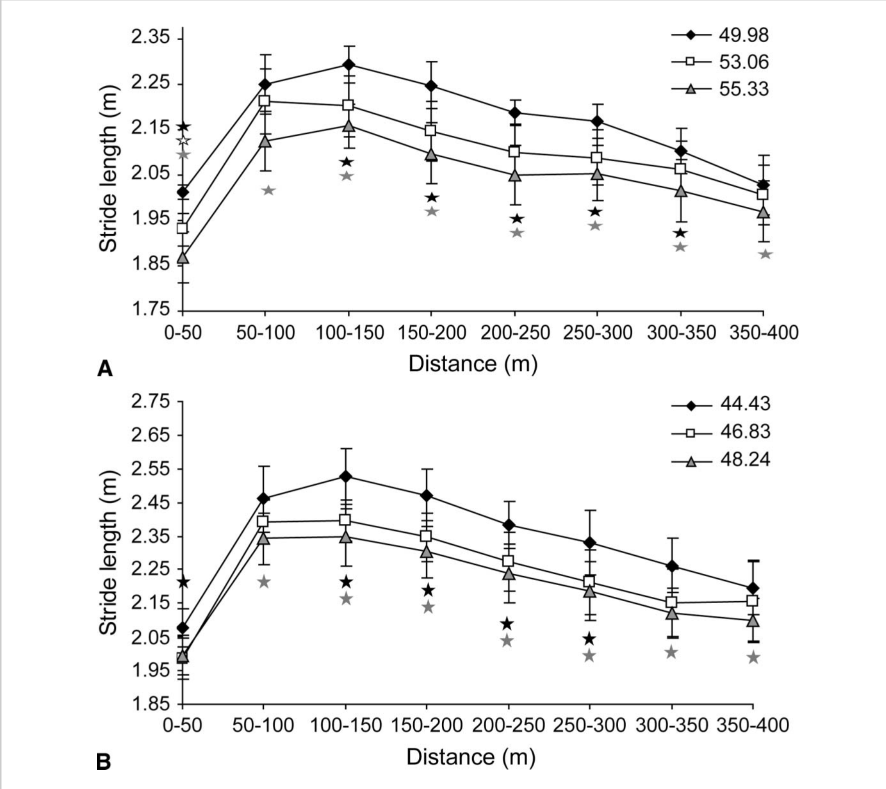

Figure 2. Time course of stride length for women (a) and men (b). For each group, $n = 5$. Black stars, gray stars, and white stars indicate that the difference is significant ($p < 0.05$) between world-class and national level, between world-class and regional level, and between national and regional level, respectively.

As observed in Table 3, the respective contributions of stride length and frequency in the velocity decrease are attributable to stride length (200–300 m), then to both stride length and velocity (300–350 m), and, finally, to stride frequency (350–400 m).

The velocity decrease is expressed as a percentage of the velocity in the previous interval. The stride length and frequency results are expressed as percentages of each parameter in the velocity decrease (Table 4).

groups (Figure 3b), the peak values for MWC, MN, MR, were 4.12 ± 0.19, 4.10 ± 0.16, and 4.00 ± 0.16 Hz, respectively. The differences between frequency values were never significantly different between groups. The decrease in the last 100 m was similar for the 3 levels of men runners.

Table 2. Size and maximal stride length of the groups.

	Women		Men	
	Size (m)	MSL (m)	Size (m)	MSL (m)
WCL	1.70 ± 0.04	2.29	1.84 ± 0.06	2.53
NL	1.70 ± 0.05	2.21	1.85 ± 0.05	2.40
RL	1.67 ± 0.05	2.16	1.81 ± 0.05	2.35

MSL = maximal stride length recorded during the 400-m run; WCL = world-class level; NL = national level; RL = regional level.

For each group, $n = 5$.

Discussion

The results reported in this study confirm that when data are recorded 50 × 50 m, the maximal and minimal values in velocity, stride length, and frequency are greater than when recorded with a precision of 100 m. The top world-level athlete is characterized by a more aggressive pacing strategy than runners at the other levels of performance (96% of the personal best at the 200-m mark) and by a greater stride length. The velocity decrease in the last part of the 400-m run was more dramatic in the world-class runners. This velocity decrease is attributable primarily to stride length (at 200–300 m), then (at 300–350 m) to both stride length and frequency, and, finally, to stride frequency in the last 50 m.

The peak velocities (10.12 $m \cdot s^{-1}$ for MWC and 8.96 $m \cdot s^{-1}$ for WWC) are about 10% greater than the velocities obtained when a race is analyzed 100 × 100 m (2,4) for the same level of performance. The peaks of velocity of the world-class, national, and regional groups are significantly different from each other ($p < 0.05$) and can be attributed to the maximal velocity of each runner and/or the pacing strategy adopted. Based on the information in Table 5, it is possible to observe that, on one hand, the world-class runners had a better 200-m best performance but that, on the other hand, they used a greater percentage of their maximal velocity (96–97% of best performance). Other investigations have shown that an all-out or a quasi–all-out strategy allows for the best results on a 60-s cycling exercise (6,7) and on a 2-minute kayak exercise (3). This could indicate greater risk-taking, supported by obvious physiological capacities allowing this risk taking. The increase in velocity was obtained by an increase in both step length and frequency as previously described by 100-m

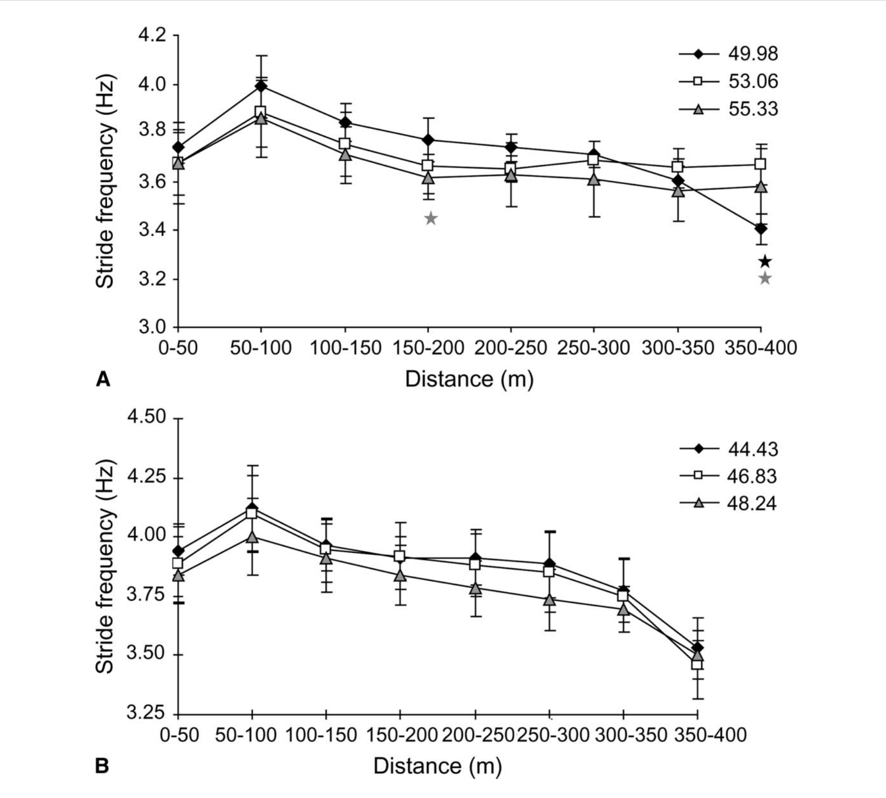

Figure 3. Time course of step frequency for women (a) and men (3). For each group, $n = 5$. Black stars, gray stars, and white stars indicate that the difference is significant ($p < 0.05$) between world-class and national level, between world-class and regional level, and between national and regional level, respectively.

analysis (9). During the 400 m, the maximal step frequency was reached during the second part of the first turn when the peak velocity was obtained. The peak stride length was achieved later, at the beginning of the first straight. One can hypothesize that these differences, when compared with the 100 m, are attributable to the presence of the curves in the track.

Stride frequencies recorded for the world-class athletes at 400 m (4.12 Hz for the men and 3.99 Hz for the women) seem to be lower compared with those recorded for the 200 m (4.50 for men and 4.48 for women) and for the 100 m (4.77 for men and 4.62 for women) (5). However, during the 400 m, the peak stride length values (2.53 and 2.29 m) were greater than the peak values recorded for the 100 m (2.43 and 2.23 m), but they were nearer to those revealed for the 200 m (2.57 and 2.39 m), particularly in men athletes. Mero and Peltola (18) conclude that relaxation times can be used to evaluate the economy of running locomotion. The particular challenge of this distance is that it has to be run very near to maximal velocity for a duration of 45 or 50 seconds. One can hypothesize that the best runners are capable of an optimal and, therefore, economical combination of length and frequency. We can hypothesize that the difficulty is in achieving a greater stride length while at the same time keeping a reserve in regard to maximal stride length, aiming to run economically and, therefore, as relaxed as possible. This capacity to exactly regulate pace is supposed to ensure the maintenance of a motor-unit reserve (23).

All the distances from 800 m to marathon are characterized by a stride frequency of around 3.50 Hz (21,10). A stride frequency greater than 4 Hz only has been recorded in the 100, 200, and 400 m and seems to be a problem when the exercise duration is greater than 1 minute. In the same way,

Table 3a. Velocity decrease from 200 to 300 m.

	Women			Men		
	WCL (%)	NL (%)	RL (%)	WCL (%)	NL (%)	RL (%)
Velocity	−4.96	−1.91	−2.5	−6.3	−7.4	−7.7
Stride length	−3.55	−2.79	−2.38	−5.7	−6	−4.8
Stride frequency	−1.59	+0.54	−0.27	−0.8	−1.78	−2.9

WCL = world-class level; NL = national level, RL = regional level.
For each group, $n = 5$.

TABLE 3B. Velocity decrease from 300 to 350 m.

	Women			Men		
	WCL (%)	NL (%)	RL (%)	WCL (%)	NL (%)	RL (%)
Vitesse	−5.84	−2.2	−2.97	−5.75	−5.2	−3.9
Stride length	−3.22	−1.43	−1.46	−3	−2.7	−3.2
Stride frequency	−2.96	−0.81	−1.38	−2.8	−2.6	−1.1

WCL = world-class level; NL = national level, RL = regional level.

TABLE 3C. Velocity decrease from 350 to 400 m.

	Women			Men		
	WCL (%)	NL (%)	RL (%)	WCL (%)	NL (%)	RL (%)
Vitesse	−8.97	−2.39	−1.81	−9.1	−7.6	−6.1
Stride length	−3.33	−2.43	−2.47	−2.6	+0.4	−0.9
Stride frequency	−5.55	+0.55	+0.56	−6.4	−7.8	−5.1

WCL = world-class level; NL = national level, RL = regional level.

TABLE 4. Comparative study between best performance in the 200-m run and the time at 200 m during the 400-m run.

	Men				Women			
	200R (s)	200T (s)	Dif (s)	%	200R (s)	200T (s)	Dif (s)	%
WCL	20.72 ± 0.05	21.22 ± 0.08	0.51 ± 0.11	97.62 ± 0.51	22.98 ± 0.29	23.80 ± 0.18	0.87 ± 0.18	96.34 ± 0.75
NL	21.09 ± 0.24	22.33 ± 0.42	1.24 ± 0.29	94.44 ± 1.21	24.29 ± 0.65	25.31 ± 0.17	1.09 ± 0.68	95.72 ± 2.66
RL	21.59 ± 0.32	23.00 ± 0.25	1.41 ± 0.52	93.89 ± 2.18	24.63 ± 0.27	26.26 ± 0.25	1.64 ± 0.19	93.77 ± 0.73

For each group, $n = 5$. WCL = world-class level; NL = national level, RL = regional level.

200R = average 200-m best performances of the runners; 200T = time at 200 m during the 400-m run; % = 200T expressed as a percentage of 200R; Dif = difference between 200T and 200R in seconds.

TABLE 5. Stride lengths and stride frequencies for different distances.

	100 m	200 m	400 m	800 m	1500 m	5000 m	10,000 m
Length (m)	2.43	2.57	2.53	2.1	2	1.8	1.75
Frequency (Hz)	4.77	4.5	4.12	3.67	3.53	3.5	3.46
ratio	1.96	1.75	1.63	1.75	1.77	1.94	1.98

Data are from Scholich (21), Brüggeman and Glad (4), and the present data (for men only).

an important difference in stride length exists between distances less than and greater than 400 m. From this biomechanical point of view, 400 m is more similar to the 200-m than to the 800-m distance. When comparing the ratios between stride length and stride frequency among distances from 100 to 10000 m (Table 5), the 400 m seems to be unique in that during this distance, stride length is more elevated compared with stride frequency.

Although the difference in velocity between the 3 levels of performance considered in the present study is attributable both to stride frequency and stride length, the only significant difference between levels concerns stride length. As seen in Table 2, although the subjects sizes are not different, their peak stride lengths are 8 cm (W) and 13 cm (M) greater for the world-class athletes than for the national athletes. The difference between the best and the less experienced runners is particularly important in the second straight and at the beginning of the second bend (100–250 m). If we compare world-class and national levels at 150 m after the onset of the race, it is possible to observe that the respective velocities (10 and 9.45 $m \cdot s^{-1}$ for the world and national levels, respectively) are only the results of differences in stride length (2.53 and 2.40 m) because the stride frequencies are similar (3.96 and 3.95 Hz). Is this result the consequence of a strategic choice, or is it an effect of muscular capacities? Previously, stride length has been shown to be correlated with the peak force occurring during the propulsion phase (16). It is therefore possible to hypothesize that one of the major differences between the best athletes and less successful athletes concerns force production during contact times.

The decrease in velocity is greater (more than 20% between the peak and the final velocities) than previously described from 100 $\times$ 100-m studies (14 to 9%) (2,4). Moreover, it is interesting to note that the decrease in velocity recorded in the last 50 m and in the last 100 m was more important for the world-class athletes than for the other levels of athletes (Tables 3 and 4), confirming that the 18% velocity decrease previously recorded with less successful athletes (20) could indicate a greater mental commitment or a better capacity to run under fatigue. This fatigue level has been shown to be particularly important in this distance as revealed by lactate concentrations greater than 20 $mmol \cdot L^{-1}$ (15), depleted values of phosphocreatine (PCr), and significant decreases of adenosine triphosphate (ATP) (12). Kinderman and Schnabel (14) have shown that the 400-m runners are able to reach very low pH (until 6.88) compared with middle-distance runners. These very low values are confirmed in elite 400-m runners (11). In the last 50 m, when the pH is supposed to be very low, both stride frequency and length decreased. The decrease in stride frequency did not differ according to level of performance. Nevertheless, in the last 50 m, the decrease in frequency was more important than the decrease in length. This decrease in stride frequency observed under fatigue has been shown to be related to the decrease in vertical leg stiffness (19). It should be noted that the difference between the peak and the final stride length was significantly greater for the world-class group than for the other groups (Figure 2a and 2b).

In a previous study, Nummela et al. (20) found that drop-jump performance was impaired by 39% after a maximal 400-m sprint; this decrease was correlated with the increase in blood lactate concentration. The electromyographic activity in the active muscles increased significantly during the 400 m, and the authors conclude that additional motor units were activated to compensate for the apparent failure of muscle contractility as a consequence of the metabolic acidosis. The progressive reduction in running speed must result from a combination of changes occurring in the muscle and a complex regulation by the central nervous system, which is based on afferent feedbacks protecting against harmful disturbances to homeostasis (23).

During the entire 400-m run, stride length rather than frequency seems to be the discriminating biomechanical parameter between levels of performance.

As suggested by Foster et al. (8), this study leads us to the conclusion that athletes adjust their pace accordingly so that they reach their critically low values of pH near the end of the race, and the hypothesis of a lower critical pH value in world-class runners compared with less experienced ones can be advanced.

Practical Applications

This study has shown that the best athletes are able to reach higher absolute and relative velocities (percent of their 200-m best performance). These higher velocities are obtained by a significantly greater stride length (2.53 and 2.29 m for the best men and women, respectively), resulting in significantly lower stride numbers (172, 179, and 182 strides for MWC, MN, and MR, respectively, and 185, 193, and 198 for WWC, WN, and WR, respectively). Moreover, world-class athletes can be characterized by a greater loss of velocity in the second half of the race, mainly attributable to a greater decrease in stride length in the last 100 m. These results demonstrate that the elite runner must be 1) a very fast runner for 200 m, 2) able to adopt an important stride length, and 3) physiologically and psychologically able to adopt a more risky strategy than the less experienced ones. From a training point of view, this means that runners have to develop the velocity of ATP-PCr breakdown–the rate at which an athlete can supply ATP via anaerobic sources (12)–but also achieve a buffer capacity to compensate for [H+] production. Furthermore, the reduction in muscle pH as a result of the fast start implies that to prevent the loss of technique that may accompany the subsequent fatigue (7), technical training sessions should be planned under fatigue to force endurance in the implied muscles.

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