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Evolution of stride and amplitude during course of the 100 m event in athletics

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ABSTRACT

Performances in sport keep improving year after year and records have now reached heights that seem very hard to beat. Among them the male athletics world record over 100 m, held by Maurice Green in 9.79s is a model of technique that will certainly require a perfect optimization of the two components to the stride - amplitude and frequency - to be beaten, or even approached again. The aim of the present study is to verify the model presented by Summers (1997) in sprinters of national calibre and to break it down into 10 m sequences, in order to evaluate more precisely the evolution of the parameters in the performance.

Among others the authors conclude that frequency cannot be considered anymore as a determinant factor to performance when national level is reached.

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1. Introduction

Performances in sport keep improving year after year and records have now reached heights that seem very hard to beat. Among them the male athletics world record over 100 m, held by Maurice Green in 9.79s is a model of technique that will certainly require a perfect optimization of the two components to the stride - amplitude and frequency - to be beaten, or even approached again.

A number of investigations have studied the criteria of efficiency in the run stride. In this context Summers (1997) presented a model that indicated speed is greatly dependent upon stride amplitude, whilst stride frequency appears to be barely significant. This theoretical model is supported by the observations made by Trouillon (1974) in subjects of regional level (12.9 s - 14 s, for 100 m), and Gazeau (1997) who studied all the 100 m races at the 1988 Seoul Olympics. In the later study however results remained very global since the analysis was based on mean values obtained in the two consecutive 50 m run sequences.

The aim of the present study is to verify the model presented by Summers (1997) in sprinters of national calibre and to break it down into 10 m sequences, in order to evaluate more precisely the evolution of the parameters in the performance.

2. Population

This study was conducted at the 1996 French National Championships. The races observed were the semi finals and final of men's 100 m, which 22 runners in total entered. The following analysis is based on

the 6 fastest and 6 slowest performances achieved, that required the definition of two groups ; the faster (F+) and the slower (F-).

The athletes' mean performances and anthropometric profiles are presented in table 1.

Table 1 : Anthropometric characteristics and performances in the two groups

Population	Height (cm)	Weight (kg)*	Performance (s)*
F+ (n=6)	181 (+ 4.4)	76.2 (+ 2.7)	10.18 (+ 0,05)
F- (n=6)	181 (+ 2.2)	71.8 (+ 2.1)	10.52 (+ 0.08)

* : significant difference between the 2 groups

3. Material and methods

The 100 m track used was graduated every 10 m with thin white marks and a total of 13 cameras (50 Hz) were used in the experiment.

Cameras 1 to 11 were positioned on the side of the track every 10 m, the first and last being on the start and finish lines, respectively. They recorded time splits for all the sprinters. For each race the filming procedure was to start recording a few seconds before the actual heat start, to film the gun fire (actual start of the video chronometer) and the passage over the respective 10 m line. Recording was then immediately stopped.

The mean speed for each 10 m zone was calculated from the split times recorded, and was adjusted taking into account the 0.02 s existing between two frames and the technical observations made by sprinting experts.

Cameras 12 and 13 were positioned beyond the finish line at the end of lanes 2 and 6 in order to record the entire run of all the sprinters, each camera filming 4 athletes after catching the gun flame.

Tape analysis was used to detect the moment of foot contact and to calculate mean stride period within each 10 m zone (period = mean time between left and right foot landing). Mean frequency and amplitude could then be calculated, as per the following equations:

- $F = 1 * T^{-1}$, where F = frequency and T = period
- $A = S * F^{-1}$, where A = amplitude and S = speed, and F = frequency

4. Statistical analysis

A one-way variance analysis plan (intra-group) by repeated measures was conducted to compare the evolution of measured parameters for each group (F+, F-) within each race.

The comparison between the groups was conducted by means of a one-way variance analysis plan (inter-group), while the comparison of the evolution of the studied parameters during the 100 m was performed by means of a two-way variance analysis plan (intra-group and inter-group).

The level of significance was set at the level $p<0,05$.

Table 2: Reaction time (RT) and split time during the entire 100m for the faster (F+) and slower (F-) groups. Times expressed in seconds.

* : Significant difference between F^+ and F^-

	F+ (s)	F- (s)	F+ - F- (s)
RT	0.17 +0.02	0.19 + 0.02	- 0.02
10 m	1.93 + 0.04	1.95 + 0.02	- 0.02
20 m	2.99 ± 0.03	3.04 ± 0.02	- 0.04*
30 m	3.95 ± 0.04	4.01 ± 0.03	- 0.05*
40 m	4.66 ± 0.05	4.95 ± 0.03	- 0.07*
50 m	5.77 ± 0.05	5.87 ± 0.04	- 0.09*
60 m	6.62 ± 0.05	6.77 ± 0.04	- 0.14*
70 m	7.49 ± 0.05	7.67 ± 0.06	- 0.17*
80 m	8.38 ± 0.05	8.61 ± 0.06	- 0.24*
90 m	9.27 ± 0.04	9.55 ± 0.07	- 0.26*
100 m	10.18 ± 0.04	10.52 ± 0.06	- 0.36*

5. Results

5.1 Split times

Table 2 presents all the split times, including Reaction Time (RT) between start and take-off from the starting-blocks.

F+ show faster times at all stages during the run; this includes RT : F+ = 0.17 ± 0.02 s; F- = 0.19 ± 0.02 s. The difference becomes significant at the 20 m mark.

5.2 Speed

The mean speeds of all 10 m sequences for both groups are reported in figure 1. Speed follows a similar pattern for both groups:

- it increases from the start line to the 60 m mark, when F- and F+ reach 11.13 ± 0.14 m.s-1 and 11.71 ± 0.11m.s-1, respectively.

However, this evolution is not homogeneous : speed increases greatly until the 30 m mark (Phase of Great Acceleration - PGA). Speed increases more than 60% between the „ 0-10 m " and the „ 10-20 m " sequences, and still more than 10% between the „ 10-20 m " and „ 20-30 m " sequences. There is no significant difference between the groups in the evolution of speed during this phase.

This increase in speed is less marked in the later sequences, no more than 5% between the „ 20-30 m " vs „ 30-40 m ", „ 30-40 m " vs „ 40-50 m " , or „ 40-50 m " vs „ 50-60 m " sequences (Phase of Minor Acceleration - PMA).

Peak speed is reached in the same sequence „ 50-60 m " for both groups, and is significantly higher in F+. F+ further demonstrates a far higher ability than F- to increase speed between the „ 40-50 m " and the „ 50-60 m " sequences, that contributes to the difference noted in the evolution of speed during this period between the two groups.

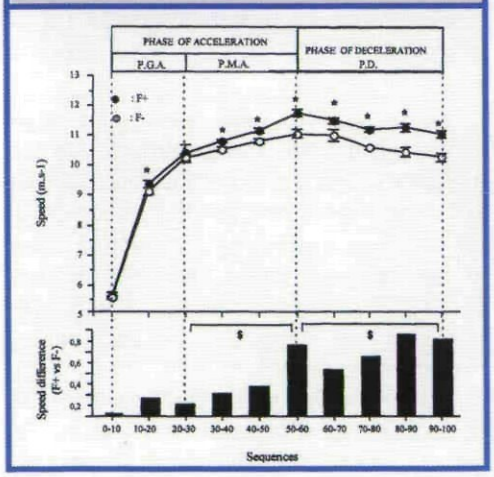
- Speed then globally decreases (Phase of Deceleration - PD) for both groups until the finish line, with a marked difference though, since F+ is actually able to limit the deterioration in speed more than F- (-6.1 % vs -7 %).

Figure 1: Mean speeds for all 10 m sequences and for both the faster (F+) and slower (F-) groups.

P.G.A.: phase of great acceleration, P.M.A.: phase of minor acceleration, P.D. phase of deceleration.

*: significant difference between the two groups for specific sequences (variance analysis by repeated measures, inter-group factor).

$: significant difference in the evolution of speed between the groups (variance analysis by repetated measures, intra*inter-group factors).



5.3 Amplitude

A marked evolution in the amplitude of the stride is noted for both groups during the course of the 100 m. Amplitude increases during the entire phase of acceleration. Such a tendency remains in F- during the „ 60-70 m " sequence (figure 2).

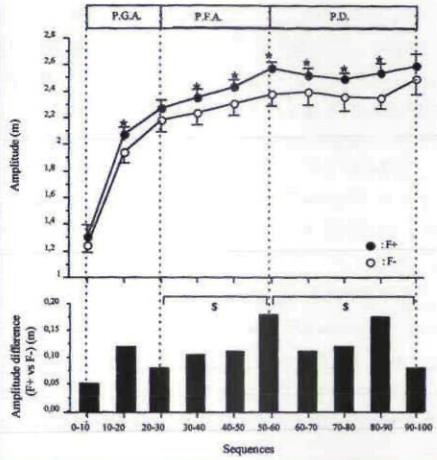
Fluctuations (representing 14 cm and 10 cm for F- and F+, respectively) are noted during the deceleration phase. For both groups, amplitude decreases then, until the „ 70-80 m " sequence and „ 80-90 m " sequence for F- and F+, respectively. A significant increase is noted for both groups in the final part of the run, associated with a marked decrease in stride frequency.

Stride amplitude is greater during all sequences of the 100 m in F+. However the evolution of amplitude between each sequence reveals some discrepancies between the two groups : during PMA,

Figure 2: Stride amplitude for the faster (F+) and slower (F-) groups during the phases of greater acceleration (P.G.A.), minor acceleration (P.M.A.) and deceleration (P.D.).

*: significant difference during a given sequence between the two groups observed by a one way variance analysis (inter-group factor).

$: significant difference in the evolution of the amplitude between the groups (variance analysis by repeated measures, intra*inter-group factor).



amplitude increases significantly more in F+ as compared to F-.

5.4 Frequency

With the exception of the „ 90-100 m " sequence, F+ always demonstrates a lower stride frequency than F- (figure 3).

Maximal stride frequencies are reached in the „ 10-20m " sequence, and „ 20-30 m " sequence for F- and F+, respectively. Therefore stride frequency peaks are reached long before speed peaks : in the middle (F-) or at the end (F+) of PGA. Marked increases in stride frequency and acceleration are therefore contemporary, especially for the slower group.

Stride frequency starts to significantly decrease during PMA, and even more during PD, for the two groups. The deterioration of stride frequency is actually so marked for F- in the final part of the run that frequency becomes lower than that of F+ in the „ 90-100 m " sequence, for the first time in the 100 m. But there is globally no significant difference in the evolution of stride frequency between the two groups, if one excepts the final sequence.

6 Discussion

The present study aimed at comparing the components of sprint running (horizontal speed, stride amplitude, stride frequency) in athletes demonstrating two significantly different levels of performance : international (10.18 s) vs national (10.52 s). Split times are faster for the faster sprinters as early as the 20 m mark, thanks to shorter reaction times inside F+.

6.1 Speed

The analysis of speed during the course of the 100 m based on 10 m sequences highlighted 3 distinct phases.

The initial phase „ 0-30 m " may be described by a greater acceleration : variations in speed between each of the three sequences concerned exceed 10 %. This observation echoes the data obtained in other studies (Vittori and Dottan 1985; Ae, Ito and Suzuki, 1992), but discriminates with the observations made by Muller and Hommel (1997), who noted a minor acceleration between the „ 10-20 m " and the „ 20-30 m " sequences. This might be explained by the fact that these authors used the instantaneous speed reached at the end of the 10 m sequence rather than the mean speed of the entire sequence.

This acceleration continues into a phase where speed keeps increasing, though less markedly (<5%), until the end of the „ 50-60 m " zone when speed reaches its maximum for both groups. Reaching maximum speed at the half-way mark has already been observed by Vittori and Dotta (1985) who have studied V. Borzov's 10.14 s performance over 100m in Monaco in 1972. More recently, Muller and Hommel (1997) analyzed the performance of all the sprinters who participated in the final of the 100 m at the 1997

World Championships in Athens and came to the same conclusion. The speed peak observed is maintained during the next 10 m sequence.

However the peak in speed observed at the "50-60 m" sequence in this study has to be related to the level of performance over the 100 m. Indeed, athletes of a lower level reach maximum speed earlier. Volkov and Lapin (1979) observed that sprinters having a 12 s personal best (PB) for 100 m reach maximum speed at the 40 m mark, while 14 s PB sprinters reach that speed at the 30 m mark. These results confirm those of Trouillon (1974) who noted that athletes performing in the range of 13-16 s reach their speed peak as early as the "30-40 m" zone. Therefore it appears that the higher the level of performance is, the later in distance the peak in speed appears, from which we may assume that high level sprinters have the ability to accelerate for a longer period. This hypothesis is further supported by a study conducted by Ae, Ito and Suzuki (1992) on the final of the 100 m at the 1991 World Championships in Tokyo. They noted that maximum speed was reached in the "70-80 m" sequence for 7 of the 8 finalists, the average time for the final being 9.96 s.

6.2 Amplitude

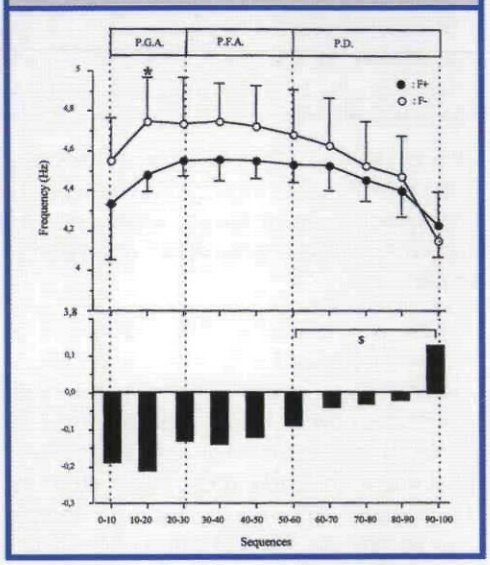
Our results suggest that high performance over 100 m is conditioned by the ability to generate a greater stride amplitude and to preserve it until the finish line; maximum amplitude is reached at the end of the phase of great acceleration (PGA), contemporary to speed peaks, after 6.60 ± 0.05 s and 6.77 ± 0.04 s, for F+ and F- respectively.

During PGA, the speed reached in both groups is very similar, but F+ is characterized by a greater amplitude whilst frequency remains identical to F-. This difference in amplitude may be the result of a greater power expressed by the faster group. In this regard, one needs to note that F+ is significantly heavier than F-. Since the population studied here is of national calibre, such a difference may hardly be due to an excess of weight, but rather to a more important muscle mass, that could be the origin of a greater power elicited during the 100 m sprint.

Figure 3: Stride frequency for the faster (F+) and slower (F-) groups during the phases of greater acceleration (P.G.A.), minor acceleration (P.M.A.) and deceleration (P.D.)

*: significant difference during a given sequence between the two groups observed by a one way variance analysis (inter-group factor).

$: significant difference in the evolution of the amplitude between the groups (variance analysis by repeated measures, intra*inter-group factor).



During the phase of minor acceleration (PMA), when F+ clearly reaches higher speeds than F-, amplitude remains the discriminant factor between the two groups. More specifically, the difference in amplitude becomes greater as the race continues, as does speed. Such a difference may be attributed again to the greater power expressed by F+. The same conclusion is drawn by Vardaxis and Hoshizaki (1989) when comparing peak net joint powers, net muscle moments and relative angular velocities in two groups of different levels (10.59 - 10.68 vs 11.68 - 12.15 s).

During the phase of deceleration (PD),

Table 3 : Mean stride amplitude (from Ae, Ito and Suzuki - 1992)
A : Top 4 finishers; B : Last 4 finishers

	Finalists (m)	A Finishers 1-4 (m)	B Finishers 5-8 (m)
0 - 10 m	1.36 ± 0.06	1.40 ± 0.09	1.33 ± 0.07
10 - 20 m	1.91 ± 0.03	1.91 ± 0.03	1.91 ± 0.03
20 - 30 m	2.36 ± 0.05	2.37 ± 0.05	2.36 ± 0.06
30 - 40 m	2.48 ± 0.09	2.51 ± 0.03	2.46 ± 0.12
40 - 50 m	2.47 ± 0.12	2.52 ± 0.12	2.43 ± 0.11
50 - 60 m	2.39 ± 0.09	2,44 ± 0.10	2.34 ± 0.06
60 -70 m	2.42 ± 0.07	2.47± 0.05	2.38 ± 0.07
70 - 80 m	2.56 ± 0.11	2.59 ± 0.10	2.53 ± 0.12
80 - 90 m	2.52 ± 0.09	2.54 ± 0.09	2.50 ± 0.09
90 - 100m	2.55 ± 0.12	2.6 ± 0.13	2.49 ± 0.09

interpreted as a phase of resistance to fatigue (Volkov and Lapin, 1979), F+ elicits a lesser reduction in speed, which may be related to the observed lesser reduction in amplitude.

These results confirm those obtained by Ae, Ito and Suzuki (1992) at the Tokyo World Championships (table 3) where great stride amplitudes have also been reported. They are similar (for 7 sequences) or greater (for 2 sequences) than those noted in our study for the group F+. In order to allow an analogy with our results, the data from Ae, Ito and Suzuki (1992) has been collated for two groups of athletes: the top 4 finishers (A) of the final versus the last 4 (B). It appears that the amplitude of A is either greater (9 sequences) or identical (1 sequence) to that of B.

The increase of speed noted with these sprinters is contemporary to the increase in amplitude. During the World Championships the peaks (for both amplitude and speed) appear later: during the „ 70-80 m " sequence, or 7.62 to 8.43 s after the start. Therefore, the higher the ability to accelerate for a longer period with a greater amplitude, the better the performance. Short acceleration and limited amplitude will not bring about world class performance (see figure 4).

The above results further support the importance of stride amplitude as a critical index to optimal performance. The race profile of a world-class sprint performance may therefore be described as follows :

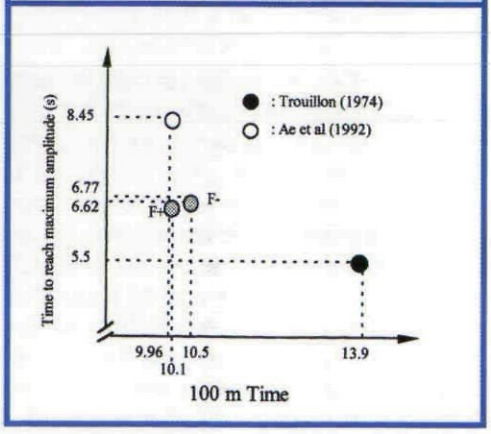
- a greater stride amplitude that is reached during a long phase of acceleration and can be sustained for 80 of the 100 metres. World-class performers are able to accelerate 1.3 s more than French National calibre sprinters
- a greater stride amplitude that can be preserved during the final phase of the race

The demand for a great stride amplitude that does not deteriorate notably in the final phase of the 100m requires a specific preparation that focuses on the development of power, muscular power and the anaerobic pathway.

6.3 Frequency

During the entire phase of acceleration, stride frequency remains statistically similar in the two groups although the frequencies of F+ are always lower (the difference always exceeds 0.1 Hz). The great variability of values inside F- (figure 3) might explain that such a difference is significant only during the „ 10-20 m " sequence.

Figure 4: Relationship between time to reach maximum amplitude stride and time for 100 m



During the deceleration phase frequency drops for both groups (differences remain non significant), but far more in F-. In the last 10 m sequence, mean frequency drops considerably more, probably as a consequence of the foreward lean position of the torso that all sprinters strategically adopt to „ dip at the line " . That momentarily increases amplitude and therefore reduces stride frequency. The magnitude of this reduction is greater in F-, an observation already made by Trouillon (1974) for the slower group.

Table 4 : Mean stride frequency (from Ae, Ito and Suzuki -1992)
A : Top 4 finishers; B : Last 4 finishers

	Finalists (Hz)	A Finishers 1-4 (Hz)	B Finishers 5-8 (Hz)
0 - 10 m	3.90 ± 0.31	3.89 ± 0.28	3.90 ± 0.39
10 - 20 m	4.76 ± 0.27	4.88 ± 0.08	4.65 ± 0.36
20 - 30 m	4.59 ± 0.12	4.58 ± 0.09	4.61 ± 0.16
30 - 40 m	4.52 ± 0.16	4.50 ± 0.13	4.53 ± 0.21
40 - 50 m	4.67 ± 0.22	4.63 ± 0.21	4.71 ± 0.25
50 - 60 m	4.79 ± 0.18	4.75 ± 0.19	4.83 ± 0.19
60 - 70 m	4.74 ± 0.14	4.72 ± 0.11	4.76 ± 0.11
70 - 80 m	4.57 ± 0.17	4.57 ± 0.13	4.56 ± 0.24
80 - 90 m	4.45 ± 0.17	4.44 ± 0.15	4.45 ± 0.20
90 - 100 m	4.38 ± 0.21	4.39 ± 0.20	4.38 ± 0.24

Therefore, although the mean frequencies of F+ appear lower than those of F-, stride frequency does not seem to constitute a discriminant factor between faster and lower sprinters.

These conclusions are not contradictory with those of Ae, Ito and Suzuki (table 4) who also note higher frequencies (for 7 of the 10 sequences) for the slower finalists of the 1991 World Athletic Championships.

However, the comparison between the stride frequency of World Championships vs National Championships sprinters reveals a significant difference for the „ 0-10 m " sequence. During this initial phase frequencies are 3.9, 4.38 and 4.55 Hz for the Tokyo finalists, the National finalists and the non finalists of the Nationals, respectively. The faster sprinters are therefore able to develop strides of greater amplitude and lower frequency in a phase when inertia is a major component against movement.

7 Conclusion

In our study where data was obtained for 10 m sequences, the faster group (F+) elicited a greater stride amplitude during the entire 100 m. This observation is in accordance with the theoretical model presented by Summers (1997), at all stages during the course of the event. This ability may be due to a greater muscular power expressed during the acceleration phases, but also to the greater ability to preserve it during the deceleration phase. In this study frequency appeared more as a means of compensation for the slower group to offset against their relative lack of power.

It seems that frequency cannot be considered anymore as a determinant factor to performance when national level is reached. It is quite clear that strength training, associated with the maximization of the anaerobic pathway, should become a major training goal to increase stride amplitude and maintain it during the entire 100 m of the event.

It remains unclear though whether this goal may be of major importance for sprinters of lesser ability.

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