

The development of velocity and acceleration in sprints

A comparison of elite and juvenile female sprinters

By Stefan Letzelter

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This study compared the development of velocity in 100m races by 22 elite and 22 juvenile women sprinters. It found that the main tendencies are the same but there are some differences between the two groups in the length and quality of the race phases. The elite sprinters are faster from the start and increase their theoretical lead continuously to the finish. They are superior in all acceleration criteria and in the length of the positive acceleration phase. The biggest difference between the two groups is in the level of maximum velocity. Much smaller, but still significant, are differences in the loss of velocity caused by fatigue and the relative velocity at the finish. The author concludes that maximum velocity and power dominate the list of priorities for the sprint abilities, that pick-up acceleration is more important than the start acceleration and that speed endurance has a much lower influence on final performance than the other abilities studied.

ABSTRACT

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they collected, the development of velocity and the abilities required for success in sprint races could be mathematically modelled:

The sprinter has to react quickly (reflex speed), accelerate as fast and for as long as possible (power), reach the highest possible running speed (maximum velocity), maintain this for as long as possible (maximum speed endurance) and minimise the loss of velocity caused by fatigue (sub-maximal speed endurance).

After the addition of more measurements, the performances of male and female elite sprinters could be analysed and the characteristics that determine differences in performance could be identified.

Until now, a similar analysis of younger sprinters had not been made. The aim of this study was to compare juvenile and elite sprinters and weigh up the differences. We

1 Introduction

At the 1987 IAAF World Championships in Athletics, researchers recorded split times of every 10m in the 100 metres races for the first time at a major international championship. From the data

analysed the races of female junior athletes aged 14 and 15 and mathematically modelled a total of 86 performances. The following comparison is based on data from 22 juvenile sprinters who recorded times faster than 13.0s at the German national championships for multi-events and the same number of elite performers, the data for which was obtained from official IAAF reports.

2 Methods

2.1 Data collection

The reaction time (t_R), 10m split times (t_{10} to t_{90}) and the final time (t_{100}) of elite sprinters were taken from the official reports from Rome 1987, Seoul 1988, Athens 1997 and Seville 1999. For the juvenile sprinters, the

LAVEG®-system (LAsEr VELOCITY Guard) was used to collect data. The instruments register the development of velocity from start to finish. The figures are produced by the system and its das3® software.

The basis for the calculation is a deductive assumption of two overlapping processes: acceleration (v_a) and the fatigue (v_f). These are both described by an exponential function and added to the model function. FUCHS (1992) has described the mathematical foundations for this modelling. The main advantage of the regression on the basis of development of distance over time is that the measured figures can be used immediately as split times and do not have to be transformed into section times and then into section velocities, which would make them prone to mistakes.

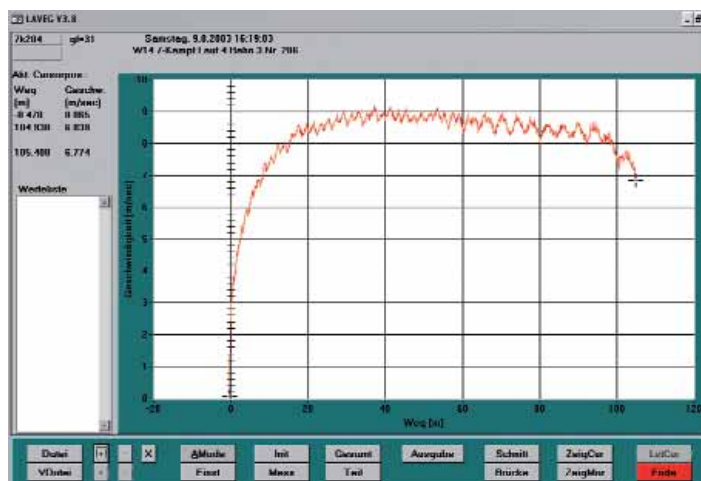


Figure 1: Presentation of the development of velocity over 100m using the das3© software

Table 1: Parameters of the model function (FUCHS, LAMES 1990)

Parameter	Meaning for the model	Original meaning
A	Speed of acceleration	Sprint speed in a race (theoretically) free of fatigue
λ	Strength of acceleration	Measure of start acceleration
B	Measure of loss of velocity due to fatigue	Time of beginning of fatigue
μ	Strength of fatigue	Increase of fatigue

Table 2: Parameters influencing sprint performance and sprint abilities

Parameters of influence	Sprint abilities	
Reaction time (t_R)	Reflex speed	
Acceleration parameters (a)	<div style="display: flex; align-items: center;"> <div style="margin-right: 10px;"> $a_{0.5}$ at 10m a_{10} at 20m a_{20} at 30m a_{30} S_1, S_1^1 </div> <div style="margin-right: 10px;"> $\left. \begin{array}{l} \text{Start acceleration} \\ \text{Pick-up acceleration} \end{array} \right\}$ </div> <div>Power</div> </div>	
Length of positive acceleration phase		
v_{max}		Maximum velocity
Length of negative acceleration phase (S_3)		Speed endurance
Relative velocity at the finish (v_z)		
Loss of time due to fatigue (t_f)		

1 S_1 : distance until $a < 0.1 \text{ m/s}^2$; S_1^1 : distance until v_{max} is reached.

2.2 Sample of parameters

In a first step, the nine split times ($t_{10}, t_{20} \dots t_{90}$) were measured. The most important performance influencing parameters are listed in Table 2. Of these t_R and $a_{0.5}$ will not be used for this comparison.

2.3 Description of data

The surveyed data is described in tables by:

- the highest (max.) and the lowest (min.) value;
- the arithmetical mean (\bar{x});
- the standard deviation ($\pm s$).

To assess performance, hypotheses of differences and changes were tested. Simple and complex statistical tests² were used to clarify if the findings are significant or coincidental. To enable the comparison of parameters in different dimensions, the results were transformed into points, similar to the system used in the Decathlon. In this way differences

between elite and juvenile sprinters could be compared, if they are measured in metres, seconds, m/s or m/s^2 .

3 Results

3.1 Final times

Only 100m races run under normal competition conditions with less than 2 m/s tail wind were taken into consideration. The average time of the young sprinters was 1.75s slower than the elite sprinters studied.

3.2 Split times

The 10m split times show that theoretical lead of the average elite sprinter over the average younger athlete grows continuously from start to finish. At 10m, the average elite sprinter is already ahead by 0.23s. On first view, the lead seems to grow in a linear way. However, its development can be shown more clearly using a parabola. In addition to a dif-

2 The first procedures are t-tests for independent and dependent samples as well as an analysis of variance with repeated measurement. When considering the question of elite female sprinters increasing their velocity from section to section more than juvenile female sprinters, the method of choice is the multi-factorial analysis of variance with repeated measurement of one factor. Test statistic is the F-value ($F_{G,P}$) für the interaction of the group (G) and the parameter (P). Before that the requirements are tested. The differences between elite and juvenile sprinters are given out in units of standard deviation ($_$ -units).

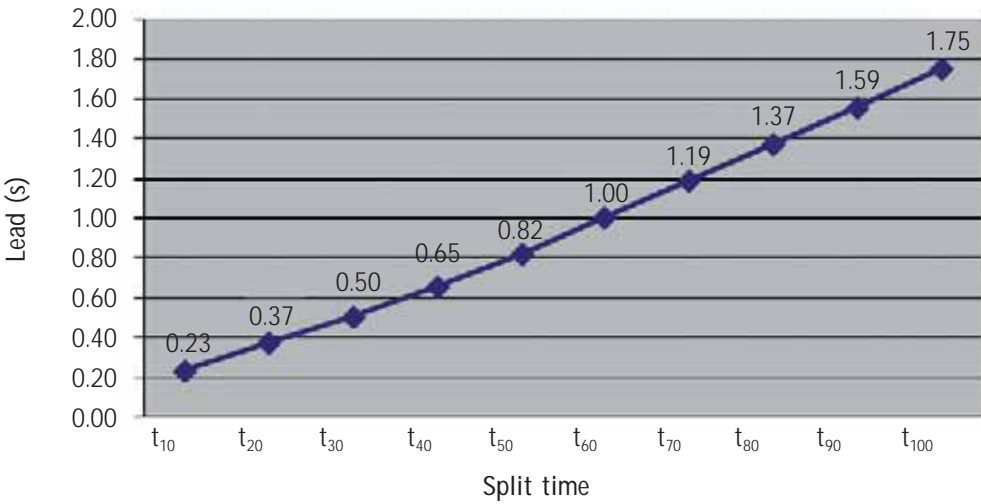


Figure 2: Development of the theoretical lead of elite sprinters over juvenile sprinters over the course of 100m

ference in the ability to accelerate, which effects both halves of the race, the second half of the race is affected by a difference in speed endurance.

3.3 Modelling for development of velocity

Figure 3 shows the velocity curves of Olympic and world champion Marion Jones (USA) ($t_{100} = 10.70s$) and the fastest juvenile sprinter studied ($t_{100} = 12.50s$). The deficits of the juvenile sprinter are obvious: she accelerates less from the start onwards. That is why the difference in velocity grows continuously until both have reached their maximum velocity. However, the difference in velocity grows very little after 30m.

The selected kinematic parameters shown in Table 4 give a more precise description of the differences.

Elite sprinters accelerate to a greater velocity and their acceleration lasts an average of 8m longer (S_1). These differences are highly significant. There is no overlay if the definition for phase of positive acceleration says it ends with a $< 0.1m/s^2$ (S_1). Then the separation of the two groups is perfect again. They are wide apart, because elite sprinters can increase their velocity for 11.22m (35.2%) longer than younger athletes. The length of the negative acceleration phase (S_2) is almost identical for both groups.

Maximum velocity is the main performance determining ability in the 100 metres, regardless of performance level. The relative velocity at the finish (v_f) and the loss of time due to fatigue (t_v) as indications for speed endurance are dependent on performance³, but to a much lower extent than the abilities of (positive) acceleration and resulting maximum

Table 3: 100m times for 22 elite and 22 juvenile female sprinters

Group	min. (s)	max. (s)	x (s)	± s	V (%)
Juvenile (14/15)	12.50	12.98	12.78	0.14	1.2
Elite	10.70	11.24	11.03	0.15	1.3

3 With both characteristics being very closely correlated ($r = 0.98; \alpha < 0.01$), from an assessment of performance point of view v_f can be negated.

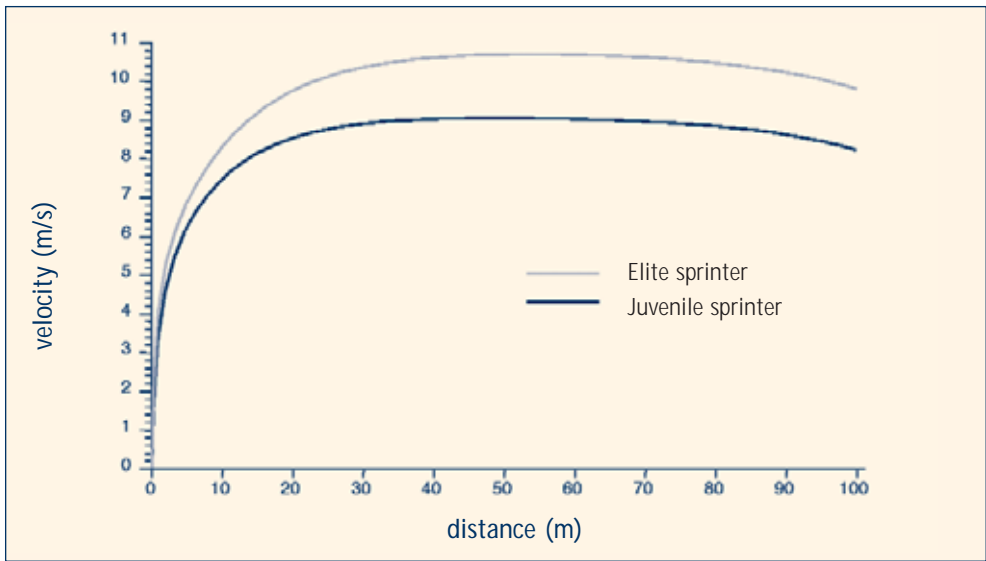


Figure 3: Velocity development for a juvenile sprinter (12.50s) and an elite sprinter

Table 4: Kinematic parameters for sprint abilities of 22 juvenile and 22 elite female sprinters

Parameter	Juvenile sprinters				Elite sprinters			
	Min.	Max.	x	± s	Min.	Max.	x	± s
a_{10}	1.18	1.33	1.24	0.045	1.67	1.84	1.75	0.045
a_{20}	0.33	0.53	0.41	0.061	0.72	0.97	0.84	0.072
a_{30}	0.08	0.20	0.13	0.034	0.28	0.47	0.37	0.055
S_1	28.52	35.89	31.92	2.146	39.14	46.52	43.14	2.290
S_3	18.34	32.17	27.70	3.156	22.38	34.43	27.89	3.779
S_t	41.52	52.28	46.18	2.644	49.45	57.69	54.03	2.269
v_{max}	8.67	9.06	8.81	0.098	10.15	10.71	10.42	0.160
t_v	0.13	0.31	0.22	0.045	0.11	0.24	0.18	0.042
v_z	84.50	94.10	89.85	2.341	88.70	94.90	91.59	2.038

velocity. The loss of time due to fatigue is only responsible for 0.04s of the difference. That is only 2.3%. This difference is barely significant. Moreover, in the velocity at the finish, the deficit of the juvenile athletes is not very great – the drop of 10.1% is not much more than the 8.4% in elite sprinters.

For a better comparison, the data from Table 4 are transformed into points and presented in Figure 5 as performance profiles⁴.

The performance profiles inform us about differences in selected parameters of influence. They are put on a list of priorities, where the

4 This is done in a way that the mean of both samples (n=44) is 0 and the deviations are presented in weighed standard deviations (σ - units).

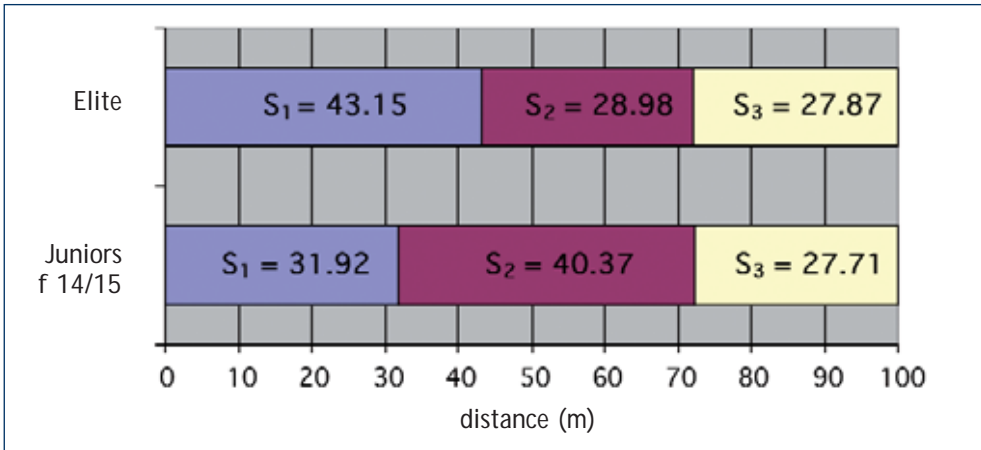


Figure 4: Phase lengths in the 100m for elite and juvenile sprinters

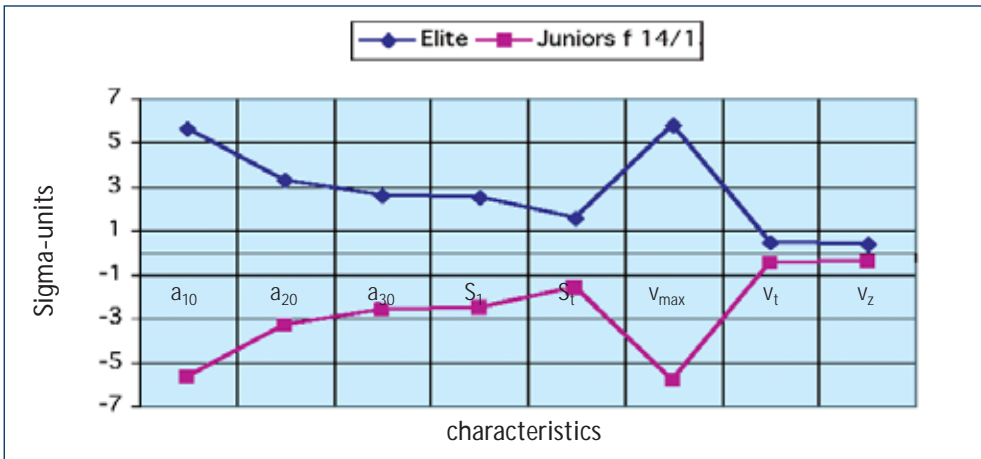


Figure 5: Performance profiles from characteristics of influence for the development of velocity and acceleration over distance in elite and juvenile female sprinters

sprint abilities are weighted according to their importance. The superior positions of maximum velocity and acceleration at 10m are obvious. Of all the other characteristics, acceleration at 20 and 30m and the length of the positive acceleration phase are more important than the loss of time caused by fatigue.

With the help of an analysis of variance the list of priorities can be secured as follows:

- The difference between elite and juvenile sprinters in v_{max} is only insignificantly larger than in a_{10} . As a result, both have the same amount of influence on the final result ($F_{GXP} = 0.70$; $\alpha > 0.10$).
- The acceleration at 20 and 30m as well as the length of the positive acceleration phase form two groups of characteristics of influence. The three differences in means vary only insignificantly ($F_{GXP} \leq 1.12$; $\alpha > 0.10$), but are significantly smaller than in v_{max} and a_{10} ($F_{GXP} \leq 5.38$; $\alpha < 0.01$).
- The ranking of the parameters of sprint endurance is secured in content as well as statistically. The differences between juvenile and elite female sprinters are significantly smaller than in the parameters of power and maximum velocity ($F_{GXP} \geq 4.81$; $\alpha < 0.05$).

4 Discussion

The development of velocity for juvenile athletes shows the same tendencies as for the elite sprinters.

Regardless of the level of performance, velocity increases, remains constant for a while and then decreases again.

While the division of the race into three phases for both groups is obvious (see Gundlach 1963 and Ballreich 1969), the lengths of the phases and the quality of the abilities involved show big differences between athletes. In fact, we know that men accelerate longer than women, adults longer than juniors, faster sprinters longer than slower sprinters. Figure 6 shows how the length of the positive acceleration phase increases with better performance.

The better the final time, the longer the distance of positive acceleration.

The constant velocity phase of the race does not get longer with a higher performance level. It is, in fact, shorter for the elite sprinters because they accelerate for longer. The phase of negative acceleration is the same length for both groups. This stands in contrast to the comparison of elite sprinters, because there, the slower sprinters lose speed earlier. But the result remains statistically unproven, because no connection was found

for the juvenile sprinters or the elite sprinters.

Even for a lower performance level, speed endurance has only a minor influence on final time. In most empiric analyses, the role of speed endurance is presented as less than 10%. The 30% figure given by Baugham et al (1984) is an overestimation.

Without a doubt, faster sprinters accelerate faster from 10 to 30m than slower sprinters. That is why faster sprinters reach a much higher maximum velocity. This is true for the male and the female elite sprinters as well as the juniors. For two groups of juvenile athletes significant differences have been found ranging from 0.5 σ (start acceleration) to 1.4 σ (acceleration at 10m).

Faster sprinters can accelerate faster and longer from the start to the maximum velocity phase.

The special importance of the transition from start to 'free' running can be seen in the fact that for elite sprinters the acceleration at 20m plays an important role. For both the elite women and juvenile athletes the correlations of acceleration at 10m and final time are similar.

Earlier analyses have already shown the leading role of maximum velocity. The connection between V_{\max} and t_{100} for the 86 juvenile sprinters studied is almost perfect at $r = 0.986$

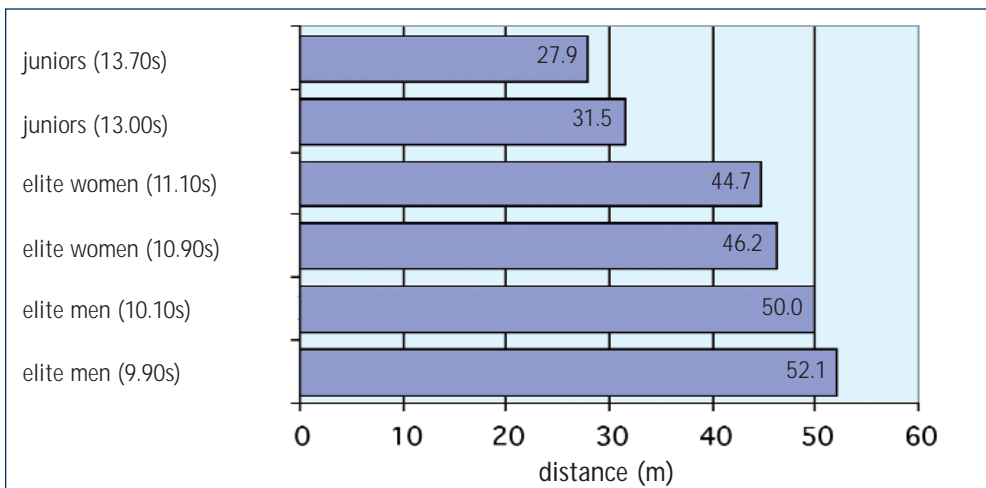


Figure 6: Length of the phase of positive acceleration for selected groups of performers

($\alpha < 0.01$). So the time t_{100} can be estimated very well over the regression $t_{100} = 24.95 - 1.38 v_{\max}$ (s). The quality of this estimation can be seen in the low standard mistake of $s_e = \pm 0.07$ s. Even within the homogenous group of elite men and women, the respective connection is highly significant ($r \geq 0.91$; $\alpha < 0.01$).

There is a close connection between maximum velocity and final time at all performance levels.

In the elite men, speed endurance plays no role. The correlations within the group of girls are significant, but of minor importance. Within elite men there is no difference at all between faster and slower sprinters. For the women the results were different depending on the way the sample was chosen. All scientific results select a catalogue of priorities in measures of influence that is independent from performance level. It is mostly identical for elite and juvenile sprinters.

5 Summary

The races of 22 elite sprinters and 22 juvenile sprinters were compared. Using split times taken every 10m – for the world class from the official reports, for the juniors with the help of the LAVEG®-system – the develop-

ment of velocity was mathematically modelled and compared with the help of selected kinematic parameters.

With regard to the tendencies in development of velocity, juvenile and elite sprinters do not differ, but there are some differences in the length of the race phases and their quality. The elite sprinters are superior from the start and increase their lead continuously to the finish. They are superior in all acceleration parameters, at 10, 20 and 30m as well as in the length of the positive acceleration phase. This is not so for the negative acceleration phase. The biggest differences can be found for maximum velocity. Much smaller, but still significant, are those for the loss of velocity caused by fatigue as well as the relative velocity at the finish.

Maximum velocity and power dominate the list of priorities of sprinting abilities, the pick-up acceleration even more than the start acceleration. Speed endurance has a much lower influence on final performance.

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