

BIOMECHANICAL CHARACTERISTICS OF SPRINT RUNNING DURING MAXIMAL AND SUPRA-MAXIMAL SPEED

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“ *Running speed is influenced by two mechanical parameters: stride length and stride rate. These two parameters have a different evolution during running. At higher running velocities, stride length levels off whereas stride rate continues to increase.*

This study demonstrates how, at supra-maximal velocity (created artificially by means of a “towing” system), these two parameters evolve differently from what could be expected on the basis of theoretical calculations. In fact, while stride length increases in a specific way, stride rate surprisingly increases less than what is expected. ”

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Introduction

Among several factors that influence running velocity, stride length and stride rate are the mechanical parameters on which it mostly depends. Sinning and Forsyth (1970) pointed out that an increase in running velocity is accompanied by a combination of increases in both stride length and stride rate, with stride rate becoming the more important factor at higher running velocities. In a study that investigated maximum effort, Bosco et al. (1984) found that stride length levelled off at high velocity, whereas stride rate continued to increase. In the light of the above observations, it seems that an increase in running speed above the maximal can be obtained by increasing the stride rate, with the possibility that stride length can in some instances even decrease. To understand further the complex phenomenon which controls running speed, this study was designed to investigate the relationship between selected mechanical parameters measured during one step cycle and running velocity performed at maximal and supra-maximal velocity.

Methods

The subjects were four male sprinters belonging to the Italian Track Team. Their anthropometric data and running records are described in Table 1. Their running records (100 m) ranged from 10.16 to 10.50 seconds.

Measurements

The runs were performed in an indoor hall. Each subject first ran a few sub-maximal runs and then three maximal runs. A series of runs were performed using a "towing" system designed by Vittori and Bosco (1983) which enabled the athletes to run at supra-maximal velocity. The towing system consisted of an electric motor connected by a mechanical device linked to a concave wheel which when the motor was switched on, reeled-up a cord of artificial material (100 m long). The other end of the cord was fixed to a belt positioned close to the athlete's centre of gravity (Fig. 1). The force was developed at uniform intensity, being transmitted through the cord to the athlete over a range of between 100-150 Newtons; the maximal velocity that could be developed was approximately 15 m per second (Vittori and Bosco 1983, Overspeed System, manufactured by Juhakoski Ky, Jyväskylä, Finland).

The running speed between 50 m and 60 m from the start was measured

with two photo-electric cells placed at those distances (Fig. 1). Stride length (SL) was obtained by measuring the distance between the footprints left by the athlete's spiked shoes on a strip of white paper fixed to the synthetic surface of part of the athletic track (Sportflex, 12 mm Mondo Rubber, Alba, Italy). A platform was placed under the section of the track between the two photo-electric cells (capacitance platform, Bosco 1980) 3 mm thick and 10 m long.

The platform was connected to two digital timers (accuracy ± 0.001 seconds) made by Ergojump Digitest, Muurame, Finland). The ground contact time (Tc) of the feet was recorded by one timer and the second timer was used to indicate the time between two successive contacts (Tf). Running velocity, in addition to being measured by photo cells (fixed at neck height) was also calculated from the stride cycle. The calculation includes both contact time and flight time. Therefore, since the stride length measured from the footprints is known (this measurement may give an error of $\pm 0.002\%$), the running velocity may be calculated as follows:

$$V_x = SL \div (T_c + T_f) \quad (1)$$

where: SL = stride length, Tc = contact time and Tf = flight time between two successive foot contacts..

Table 1 - Physical characteristics and running records of the four male sprinters studied (means \pm standard deviation)

Age (years)	Mass (kg)	Height (cm)	Leg length (cm)	Record 100 m (s)
21,5 \pm 2,1	69,0 \pm 7,0	177,3 \pm 1,9	90,9 \pm 0,8	10,33 \pm 0,13

Results

In order to compare selected mechanical attributes during sprint running performed at maximal and supra-maximal speed, the best trials of both performances were chosen for statistical analysis (Table 2). Stride length, stride rate and contact time measured for both maximal and supra-maximal velocity are plotted against the running speed in Fig. 2. As expected during normal running conditions, stride rate increased with running speed; on the other hand, stride length after an initial increase levelled off and then decreased as the speed reached the maximal value. Contact time decreased with increased running speed. During supra-maximal velocity, in contrast to what was expected from theoretical estimation, stride length increased as the running speed increased. Similarly,

stride rate showed a different pattern from what was observed during normal maximal speed; in supra-maximal sprinting it tended to increase at a much lower rate than the projected rate for normal sprinting at maximal speed. The contact time reduced at a lower rate than that for natural maximal sprinting.

The flight time correlated negatively with the running speed during normal maximal velocity; however as the running velocity increased during supra-maximal speed, no further decrease could be observed (Fig. 3). The ratio between contact time/stride cycle total time ($Ct \div Tt$) remained unchanged as the running speed increased during maximal effort; the same trend was observed during supra-maximal speed although the ratio showed a lower value (Table 2).

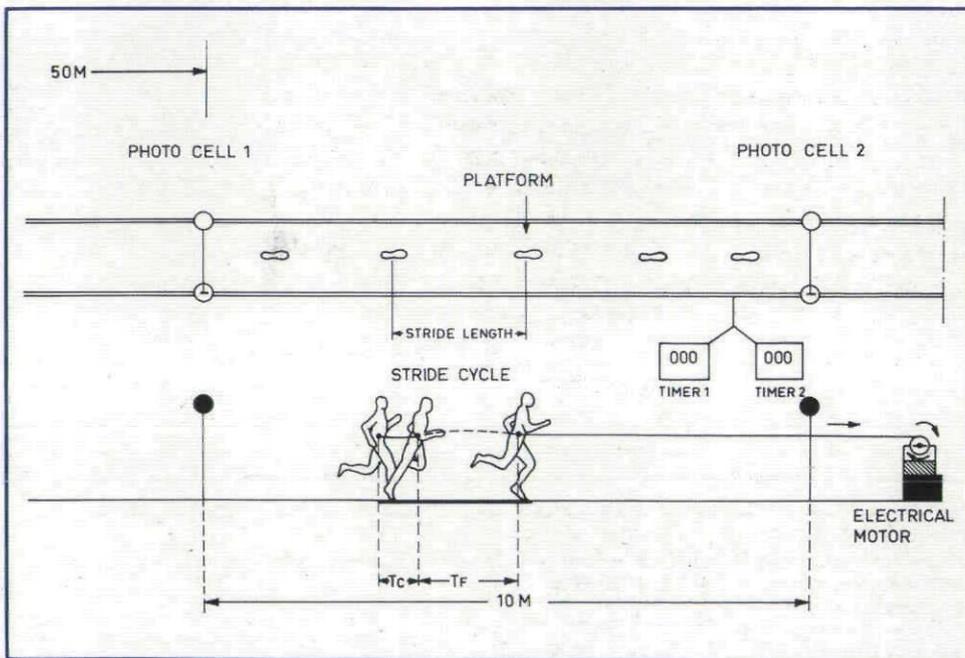


Fig. 1 - Schematic representation of the apparatus used

Table 2 - Mean \pm SD of selected mechanical parameters calculated from the best trial performed during maximal and supramaximal velocity

Running speed conditions	* Horizontal velocity $m s^{-1}$	Stride length cm	Stride rate (Hz)	Contact time ms	Flight time ms	C_f/T_f %
normal max	10,15 \pm 0,42	225,8 \pm 4,3	4,5 \pm 0,3	92,8 \pm 3,1	130,0 \pm 10,6	41,6 \pm 1,5
pulling supramax	11,60 \pm 0,92	244,8 \pm 9,7	4,7 \pm 0,7	84,9 \pm 6,9	126,0 \pm 5,7	40,1 \pm 1,0
Significance of difference	P<01	P<02	NS	P<01	NS	NS

* The horizontal velocity was calculated from formula 1.

The difference between the two conditions was tested with Student's t-test (paired observations)

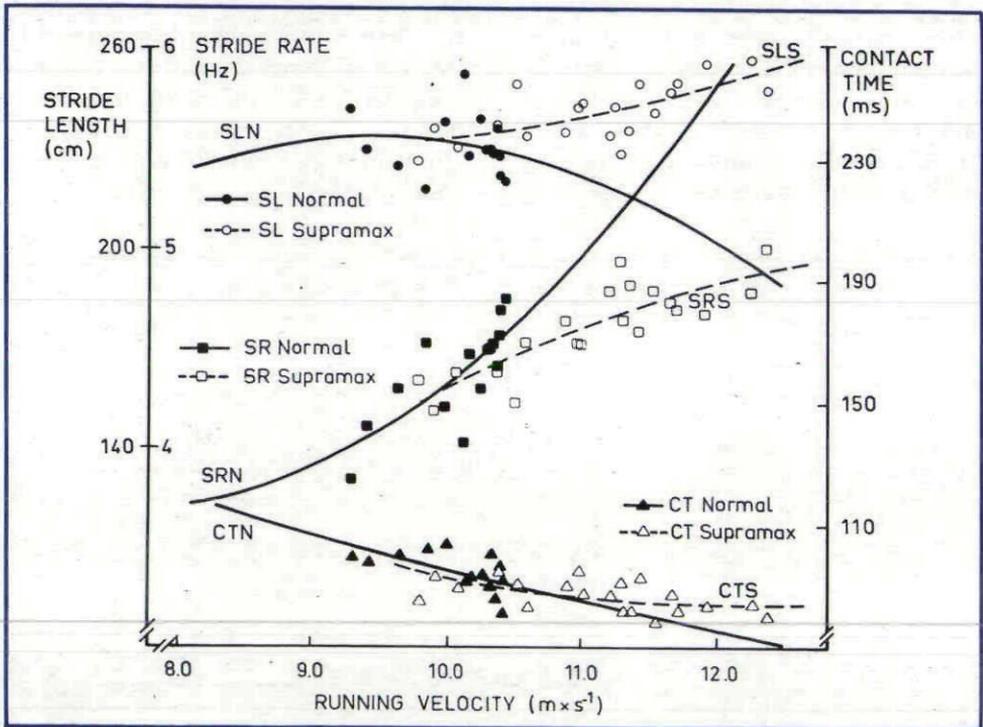


Fig. 2 - Contact time, stride length and stride rate, are presented in function of speed recorded during running performed in both normal and pulling conditions

Regression equation for contact time normal: $y = 268,49 - 23,21 x + 0,60 x^2$

contact time supramax.: $y = 111,25 + 39,79 x - 1,97 x^2$

stride length normal: $y = -658,95 + 183,94 x - 9,47 x^2$

stride length supramax.: $y = 359,88 - 29,8 x + 1,72 x^2$

stride rate normal: $y = 15,24 - 2,72 x + 0,16 x^2$

stride rate supramax.: $y = -2,91 + 1,10 x - 0,04 x^2$

Discussion

Maximal running speed is reached during natural locomotion by an increase in stride rate, which can be accompanied by a levelling off or even a slight decrease of stride length. This phenomenon has been observed in earlier experiments (e.g., Högberg 1952, Sinning & Forsyth 1970, Bosco et al. 1984) and confirmed in the present investigation (Fig. 2). However, the reason why stride length levels off at maximal speed or even may decrease has not been as yet demonstrated. Cavagna et al. (1976) suggested that

this phenomenon is probably due to anatomical limitations. It should be remembered that stride length is the sum of the athlete's horizontal displacement of the centre of gravity (CG) during both contact (L_c) and flight times (L_f) (see Table 2). The horizontal displacement of the CG when the foot is in contact with the ground is given by the following formula (Cavagna et al. 1976):

$$L_c = V_x \cdot T_c \quad (2)$$

where: V_x = horizontal velocity and
 T_c = contact time.

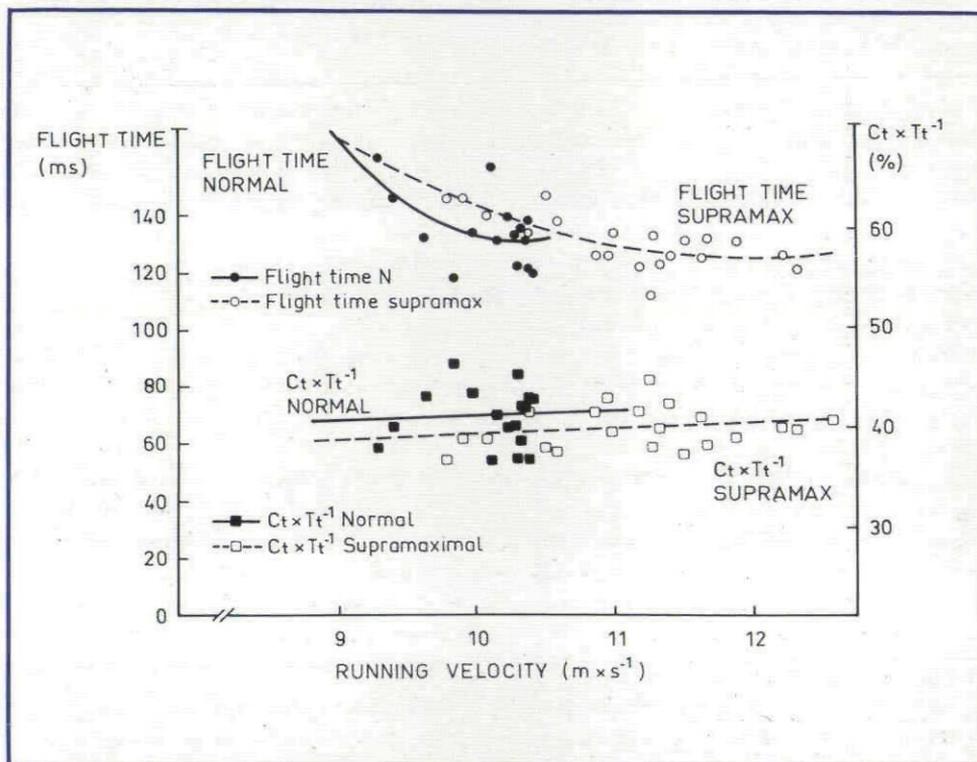


Fig. 3 - Flight time and the ratio contact time/total cycle time are presented as a function of the speed recorded in both normal and pulling conditions

Regression equation for flight time normal: $y = -580,13 + 160,87x - 8,9x^2$

flight time supramax.: $y = 791,53 - 110,99x + 4,62x^2$

ratio contact time/total time normal: $y = 192,24 - 30,38x + 1,53x^2$

contact time/total time supramax.: $y = -130,30 + 30,36x - 1,35x^2$

The displacement of the CG during flight can be calculated as follows:

$$L_f = V_x \cdot T_f \quad (3)$$

where: V_x is as in formula 2 and
 T_f = flight time between two successive contacts.

Since the L_c , above a given speed is maintained constant (Cavagna et al. 1976), then the stride length becomes a function of both T_f and running speed. Therefore as the running speed increases, stride length is kept constant by a decreasing flight time (Fig. 3).

However, the present findings demonstrated that the increase in speed from maximal (10.15 m per second) to supra-maximal (11.6 m per second) obtained through the pulling system, was produced by a statistically significant increase ($P < 0.02$) in the stride length (Table 2). The stride length, in contrast to what was expected, increased as the running speed increased. This was obtained because the flight time and contact time did not show the expected decrease. Therefore, at supra-maximal speed both the horizontal displacements of the CG during contact and flight (L_c and L_f) demonstrated a slight increase, compared to that observed at maximal speed (Table 2). In addition, stride rate increased at supra-maximal speed, even if it was not statistically significant (Table 2).

The physiological implications are very difficult to point out from the present experiment. However, it is interesting to note how stride rate was not increased as much as expected. This suggests that some neural mechanism limits speed movement when muscles are developing a certain amount of force, since it is possible to reach a greater

frequency in cycling (5.5 to 7.1) at low force output. If the implications connected with supra-maximal speed are difficult to be explained, the present results seem to be very interesting from a training point of view.

Until now the most popular methods which have been used in sprint improvement programmes have been:

- 1) Downhill running (e.g. Petrovsky)
- 2) Towing (e.g. Slator Hammel)
- 3) Treadmill sprinting (e.g. Dintiman)
- 4) Rubber rope horizontal pulling (e.g. Vittori)
- 5) Rubber rope horizontal and vertical pulling system using a motor drive (e.g. Kutznezov).

Downhill running has been used largely in the world. However, not all agree about the beneficial effect attributed to this method. The opponents point out that this system may actually reduce stride length, limiting the pushing phase even if the stride (rate) is increased.

Towing has been performed with a pacing machine consisting of a towbar and handle attached to the rear bumper of an automobile. An increase in the stride length and stride rate has been observed after training with this towing system (e.g. Dintiman 1978). Nevertheless the application of this method is rather difficult because the arm movements cannot be performed since the hands must grip the handle.

Treadmill running has also been used for sprint training. However, no significant effects have been shown, although an improvement of stride rate can be supposed. Horizontal pulling with rubber rope has been used frequently as an overspeed tool (e.g. Vittori 1970, Locatelli & Bosco 1978, per-

sonal communications). This system offers many difficulties; first the pulling force is not constant being greater at the start and decreasing dramatically as the athlete moves forwards. Initially because of the high pulling force the stride frequency is much higher than that reached under normal conditions. However, as the athlete progresses into the sprint run, the pulling effect decreases and thus the speed changes accordingly. Therefore the total biomechanical profile of the run is completely changed and may have a deleterious effect on the training strategy. A motor driven pulling system has been devised recently (see Kutznezov); it drives the athlete upwards and forward by means of an elastic rope connected to a motor drive system operating on the ceiling of an indoor hall. The speed reached with this system can be very high. However, the physiological benefit is in doubt. Even if overspeed training has been used to try to improve stride length and stride rate, it should be pointed out that it is a powerful system to stimulate the leg muscles. It is well documented that as the stretching speed of the muscles increases their tone is proportionally improved. This leads to the development of a

great amount of force and elastic energy in a short period of time (Bosco et al. 1981). Similarly, as the running speed improves so the ground reaction forces are also increased (e.g. Bosco et al. 1985) due to the improvement of the muscle tone. Therefore overspeed training should be used mainly to stimulate and to increase the development of muscle tone. However, using the pull up driving equipment (Kutznezov) part of the load which should stimulate the leg muscle is taken up by the pulling system, decreasing thus the possibility of improving the stimulus which might develop an increase of muscle tone. In the light of the above observations, it seems that the new method used in this experiment is suitable to improve both biomechanical parameters and to stress properly the physiological system of the athlete without changing the basic mechanisms governing the running pattern.

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