

## KINEMATIC AND DYNAMIC CHARACTERISTICS OF MAXIMAL SPEED IN YOUNG SPRINTERS

Milan Čoh<sup>1</sup>, Branko Škof<sup>1</sup>, Otmar Kugovnik<sup>1</sup>, Aleš Dolenc<sup>1</sup>, Tomaš Kampmiller<sup>2</sup>, Eugen Laczo<sup>2</sup>, Roman Holček<sup>2</sup>, Peter Šelinger<sup>2</sup>

<sup>1</sup> Faculty of Sport, Ljubljana, Slovenia, <sup>2</sup> Faculty of Physical Education and Sport, Bratislava, Slovakia

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### Abstract:

*Sprinting speed is a complex ability whose physiological basis is mostly genetically defined. Top competition results are therefore as a rule attainable only for a small, select number of individuals.*

*The purpose of this study was to find the most important kinematic and dynamic parameters, their developmental trend and their influence on the efficiency in maximal sprinting speed for young sprinters of both sexes, from eleven to eighteen years of age. We recorded kinematic and dynamic parameters with locomometer. The vertical pressure on the surface was calculated by biomechanical modelling of running steps. We calculated correlation between maximal sprinting speed and kinematic and dynamic parameters.*

*The results show, for both sexes, that the structure of the sprint stride changes drastically in connection to the stride length and frequency, the ratio between the contact and the flight phases and the vertical pressure on the surface.*

*The correlation coefficients show that the duration of contact ( $R=0.71$ ), the relative stride frequency ( $R=0.52$ ) and the vertical pressure on the surface ( $R=0.89$ ) are good indicators of the sprinting potential of young runners.*

**Ključne riječi:** *sprint, kinematics, dynamics, diagnostics*

### Sažetak

#### KINEMATIČKE I DINAMIČKE KARAKTERISTIKE MAKSIMALNE BRZINE KOD MLADIH SPINTERA

Brzina sprinta je kompleksna sposobnost čija se osnova većinom definira genetički. Vrhunske natjecateljske rezultati stoga u pravilu može postići samo mali broj odabranih pojedinaca.

Svrha ovog istraživanja bila je naći najvažnije kinematičke i dinamičke parametre, njihov trend razvoja, te njihov utjecaj na efikasnost maksimalne brzine sprinta kod mladih sprintera oba spola, a od 11 do 18 godina starosti. Kinematički i dinamički parametri snimani su lokometrom. Okomiti pritisak na površinu izračunat je biomehaničkim modeliranjem trkačkih koraka. Izračunali smo korelaciju između maksimalne brzine sprinta, te kinematičkih i dinamičkih parametara.

Rezultati pokazuju, za oba spola, da se struktura sprinterskog koraka drastično mijenja s obzirom na duljinu koraka i frekvenciju, omjer između faze kontakta i faze leta, te okomitog pritiska na površinu.

### Zusammenfassung

#### KINEMATISCHE UND DYNAMISCHE CHARAKTERISTIKEN DER MAXIMALEN GESCHWINDIGKEIT BEI JUNGEN SPINTERN

Die Geschwindigkeit des Sprints ist eine komplexe Fähigkeit, deren physiologische Basis meistens genetisch definiert wird. Spitzenwettkampfergebnisse sind deswegen in der Regel nur für eine geringe Anzahl von Sportlern erreichbar.

Die Absicht dieser Forschung war die wichtigsten kinematischen und dynamischen Parameter zu finden, ihre Entwicklungstendenzen und ihr Einfluß auf die Effizienz bei der maximalen Geschwindigkeit des Sprints bei den jungen Sprintern beider Geschlechter im Alter von 11 bis 18 Jahre festzustellen. Wir haben die kinematischen und dynamischen Parameter mittels des Lokometers aufgenommen. Der senkrechte Druck auf die Fläche wurde mittels der biomechanischen Modellierung von Laufschritten berechnet. Wir haben auch die Korrelation zwischen der maximalen Geschwindigkeit des Sprints und den kinematischen und dynamischen Parametern berechnet.

*Korelacijski koeficijenti pokazuju da su trajanje kontakta (R=0.71), relativna frekvencija koraka (R=0.52), te okomiti pritisak na površinu dobru (R=0.89) indikatori sprinterskog potencijala mladih sprintera.*

**Ključne riječi:** *sprint, kinematika, dinamika, dijagnostika*

*Die Resultate zeigen, daß, für beide Geschlechter, die Struktur des Sprintschrittes bedeutend geändert wird in Bezug auf die Länge des Schrittes und die Frequenz, in Bezug auf das Verhältnis zwischen den Kontakt- und den Flugphasen als auch in Bezug auf den senkrechten Druck auf die Fläche.*

*Die Korrelationskoeffiziente zeigen, daß die Dauer der Kontakt (R=0.71), die relative Schrittfrequenz (R=0.52) und der senkrechte Druck auf die Fläche gute (R=0.89) Indikatoren des Sprintpotentials bei den jungen Läufern sind.*

**Schlüsselwörter:** *Sprint, Kinematik, Dynamik, Diagnostik*

## INTRODUCTION

Maximal sprinting speed, undoubtedly the most important factor of competitive sprinting efficiency, is mostly dependant on neuromuscular processes, the cyto-histologic structure of the muscles, explosive power potential, dynamic flexibility, biochemical processes and the level of proficiency in the motor stereotype - technique. Different emphasis is given to the individual factors at different stages in the developmental process of the sprinter. The basic problem in the methodics of sport training is undoubtedly connected with the choice of relevant training means that form a suitable and efficient training process. Mastering the efficient technique is one of the priority goals in the early phase of the development of young sprinters. Other factors, namely manifest themselves through the technical model of sprint (Gambetta, 1991).

A high degree of movement standardisation is present, although in running, which is the most elementary mode of movement significant differences appear in the execution efficiency of the technique, especially in sprinting. According to Tabachnik (1991) the most appropriate biological age for mastering the efficient technique is between 7 and 13. A programmed training process is decisive for future results in sprinting.

Maximal sprinting speed is manifested through two basic parameters: stride length and frequency. Both components are closely correlated. Their relation is very individually conditioned and automated in the central regulation of movement according to the sprinter's motor abilities and morphological characteristics (Ionov and Černjajev, 1968). Stride frequency and length as well as the factors which influence their size, change significantly in the course of the sprinter's development. In fact, the training process is, fundamentally, oriented toward finding an optimal proportion between the two components.

The purpose of this study is to find the kinematic

and dynamic parameters, their dynamics and degree of correlation with maximal sprinting speed of young male and female sprinters aged from 11 to 18.

## METHODS

### Subjects

The subject sample consisted of 27 young male and 35 young female sprinters, members of six Slovene track and field teams. According to age they were grouped into four categories:

- male sprinters, 11-14 years of age (n=15) (weight 162.7 ± 12.6 cm, mass 49.7 ± 12.5 kg)
- male sprinters, 15-18 years of age (n=12) (weight 174.8 ± 4.1 cm, mass 66.4 ± 6.6 kg)
- female sprinters, 11-13 years of age (n=15) (weight 159.3 ± 9.6 cm, mass 46.2 ± 5.1 kg)
- female sprinters, 14-16 years of age (n=20) (weight 166.9 ± 5.8 cm, mass 52.9 ± 5.1 kg)

### Procedures

The project for measuring maximal sprinting speed parameters emerged from cooperation between the Institute for Kinesiology of the Faculty of Sport in Ljubljana and the Faculty of Physical Education and Sport (Fakulta telesnej vichovy a sportu) in Bratislava. The primary instrument used to register kinematic variables was the LOCOMOMETER (Fig. 1), (Kampmiller et al., ).

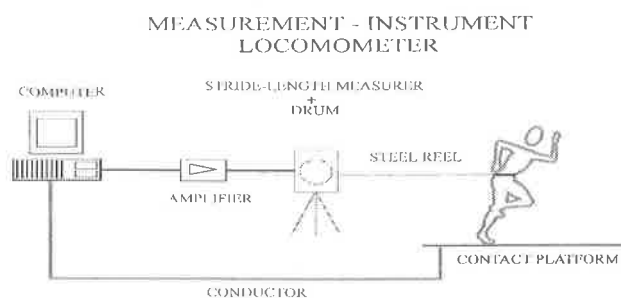


Figure 1

**Variables**

The following kinematic variables were used in this procedures:

**Kinematic variables:**

- Duration of contact with the surface (ms)
- Flight duration (ms)
- Stride frequency (number of strides/sec.)
- Stride length (cm)
- Activity (flight duration/contact duration)
- Relative stride length 1 (stride length/body height)
- Relative stride length 2 (stride length/leg length)
- Relative frequency (frequency x body height)
- Vertical pressure (N)
- Relative vertical pressure

**Morphologic variables:**

- Body height (cm)
- Body weight (kg)
- Leg length (cm)

**Criterion variable:**

20 m sprint with running start (m/s)

The measurement procedure is based on a joined current flow (12 V), the first pole being the runner, towing a steel reel (diameter 0.005 mm). The speed of unravelling is registered by a digital counter, which sends impulses through the scanner and the amplifier into the computing unit. The second pole is represented by a contact platform on which the sprinter is running. This surface is moistened with an electrolyte (NaCl). The individual contacts of the running-shoes with the surface are registered by the apparatus as contact and flight phases of the running stride.

In running sprint we started from the fact that running is a series of jumps in the horizontal plane. In individual jumps we have the following values: length of jump (D), horizontal component of flight speed (Vx), flight duration (T), contact duration (t) and body mass of the runner (m). The duration of contact with the surface is composed of amortisation (compensation) and extension. In regard to some previous studies (Ozolin, 1986), the extension phase (t1) is 60 % of the complete contact duration. S (to) is the marked duration of amortization.

The following equations are valid in this case:

$$D = \frac{2}{g} * Vx * tg \alpha \tag{1}$$

where alpha is the flight angle of the centre of gravity

$$Vy = Vx * tg \alpha \tag{2}$$

where vy is the vertical component of flight speed

From the above equations we can calculate the speed Vy

$$Vy = \frac{Dg}{2Vx} \tag{3}$$

The vertical component of the pressure of surface at the time of the push-off is marked by Fp by the following equation:

$$\int_{t_0}^t (\bar{F}_p * (t) - mg)dt = m * vy \tag{4}$$

We mark the force Fp by an integral with the limited average value of Fp and have the following dependence:

$$\int_{t_0}^t \bar{F}_p * dt = m(\frac{Vx}{t1} + g) \tag{5}$$

For the calculation of the relative value of vertical pressure the following equation holds:

$$\left(\frac{\bar{F}_p}{m} - g\right) \frac{1}{g} = \frac{D}{2Vx * t1} = \frac{D}{1.2 * t * Vx} \tag{6}$$

By further procedure the basic statistical parameters were calculated for all variables, the differences between the subject samples in kinematic and dynamic variables were defined, and the correlations between the variables and the criterion were calculated.

**RESULTS**

Statistically significant differences exist between the age groups of sprinters (Table 1) in all the used parameters, except the absolute stride frequency and the duration of the flight phase. The groups differ chiefly in the following parameters: absolute

Table 1: Kinematic and dynamic parameters of maximal speed for male and female sprinters of different ages (X: mean value, SD: standard deviation)

Sprinters	MALE					FE		MALE		
	11-14 n=15		15-18 n=12			11-13 n=15		14-17 n=20		
Parameters	X	SD	X	SD		X	SD	X	SD	
Body height	162.7	12.6	174.8	4.1	**	159.3	9.6	166.7	5.8	**
Leg length	93.1	8.9	100.3	2.8	*	92.5	5.1	95.8	3.4	*
Body weight	49.7	12.5	66.4	6.6	**	46.2	8.3	52.9	5.1	*
Duration of contact	128	13.3	107	7.5	**	123	7.3	118	12.8	
Duration of flight	117	15.6	127	9.3		128	12.4	128	12.4	
Stride frequency	4.1	0.2	4.3	0.2		4.00	0.2	4.08	0.2	
Stride length	179	21.5	205	13.2	**	181	15.1	188	9.2	
Speed	7.32	0.7	8.80	0.6	**	7.23	0.4	7.65	0.5	*
Activity	0.93	0.1	1.20	0.1	**	1.04	0.2	1.09	0.2	
Rel. stride length 1	1.10	0.0	1.18	0.0	**	1.14	0.1	1.12	0.1	
Rel. stride length 2	1.92	0.1	2.06	0.1	**	1.95	0.1	1.96	0.1	
Relative frequency	6.64	5.8	7.50	2.9	**	6.34	3.8	6.78	4.3	*
Vertical pressure	1285	35.6	1853	9.8	**	1236	24.3	1436	14.9	*
Rel. vertic. pressure	15.88	16.1	18.11	10.5	**	16.97	11.0	17.33	16.9	

\*\* P<0.01 \* P<0.05

and relative vertical pressure, contact duration and stride length, as well as relative frequency. The presented parameters have a common basis in the neuromuscular efficiency, which is manifested mostly in the push-off pressure. Changed relations between the duration of contacts and flight phases (activity - 78%) point to this.

Differences in maximal speed among female sprinters (Table 1) occur mostly on account of the differences in morphological measures and less as a consequence of differences in the kinematic and dynamic parameters, with the exception of vertical pressure and relative frequency.

For male sprinters (11-14 years old) the contact

phase is longer than the flight phase, for female sprinters of the same age category this relation is just the opposite. The tendency for further development goes toward shortening the contact phases and lengthening the flight phases, both for males and females. This is most evident for male sprinters from 15 to 18 years of age. The proportion of the contact phase in the duration of the running stride is 52% for the 11-14 year old male sprinters and only 46% for the 15-18 year group. With female sprinters no significant changes were noted in the duration of the contact phase. Together with quantitative changes, the structural changes - or rather the relation between the contact and the flight phases occur with young sprinters. The process of

TABLE 2: Correlation coefficients of kinematic and dynamic parameters with maximal sprinting speed

Sprinters	MALE				FEMALE			
	Age: 11 n=	14 15	Age: 15 n=	18 12	Age: 11 n=	13 15	Age: 14 n=	17 20
Body height	.84	*	.08		.50		.56	*
Leg length	.78	*	.03		.36		.45	*
Body weight	.84	*	.40		.22		.33	
Duration of contact	-.41		-.71	*	-.69	*	-.67	*
Duration of flight	.33		.19		.09		.04	
Stride frequency	.01		.56	*	.63	*	.65	*
Stride length	.78	*	.61	*	.68	*	.82	*
Activity	.83	*	.56	*	.53	*	.60	*
Rel. stride length 1	.49		.34		.51	*	.46	
Rel. stride length 2	.53	*	.49		.22		.28	
Relative frequency	.43		.52	*	.30		.32	
Vertical pressure	.89	*	.56	*	.74	*	.50	*
Rel. vertic. pressure	.58	*	.41		.38		.43	*

\* P<0.05

training young sprinters should be oriented precisely towards changing the quality of the sprinting stride and approaching the modality of top sprinters, where the relation of contact-flight phase is 43% against 57% for male sprinters and 45% against 55% for female sprinters (Lopez, 1990).

The change in the quality of the running stride between the age categories can also be seen in parameters of frequency and especially in stride length. The latter increases for male sprinters by an average of 24 cm and by 11 cm for female sprinters. The stride length is connected both with the development of motor and morphological factors. Body height, or better yet, the leg length, indisputably decisively forms the running stride. The index of relative stride length shows the extent to which the stride length is optimised to the body height. An optimal index for top male sprinters is 1.20 - 1.25 (Gambetta, 1991), in our data it is the male sprinter group 15-18 years of age that is closest to these values.

Stride length is undoubtedly connected with the vertical pressure developed on the surface by the runner. The mean value of the vertical pressure of the foot on the surface for the 11-14 year old male sprinters group is 1285 N and a massive 1853 N for the older male group, representing almost three times the mean body weight of the sprinters. The value is 1236 N for the younger female sprinters and 1436 N for the older group, being about two and a half times their mean body weight. Top sprinters develop a reaction force of the surface in the order of 2800-3100 N (Ozolin, 1986).

In light of the results in Table 2, we can state that the morphological parameters: body height, leg length and body weight have a high positive correlation with maximal speed in the 11-14 year-old male sprinters group. Both longitudinal measures are also positively correlated with maximal speed in 14-17 female sprinters group, but this correlation is less evident. The importance of the longitudinal measures, especially leg length, should be treated in context with the stride length parameter, which is in high correlation with maximal speed for all runners.

The variability of results in the maximal sprinting speed was connected mostly by relative frequency, stride length, duration of contact and vertical pressure, this being valid for sprinters of both sexes and all categories.

## DISCUSSION

Sprinting is a continuous series of "jumps" in the horizontal plane this sprinting speed demands the development of as much pressure on the surface as possible. Together with the degree of this pressure, its frequency of occurrence by contact of feet with the track is also significant. The duration of the contact phase and of the flight phase varies significantly in different quality categories of sprinters. There is a general rule that in better sprinters the duration of contact is shorter, while the duration of the flight phase is longer. It is just the opposite in lower quality sprinters. Sprinters of top international quality have a 85 or less millisecond contact duration, while the flight phase lasts up to 130 milliseconds, that is from 55% to 60% of the duration of the complete stride cycle (Gambetta, 1991).

The contact phase of the sprint stride consists of two parts: forward support phase - amortisation and back support phase extension. The execution of the contact phase is connected with the excentric-concentric mode of muscle contraction. In the first phase (amortisation) the stretching of the extensors of the jump, knee and hip rings occurs, due to external pressure, which is greater than the strength of the mentioned muscle groups. Amortisation is followed by the concentric mode, that is the sprinters push-off from the surface. The regulation of muscle activity in excentric and concentric contraction is based on the physiological laws of muscle strength development. In excentric-concentric contractions it was found that a greater efficiency of the push-off occurs due to the exploitation of elastic energy which is saved during excentric contraction (Bosco et al., 1976, Bosco, 1985). Most of the elastic energy can be saved in muscles. This depends on the speed of extension of external pressure and on the number of active transversal bridges. For the occurrence of transfer of elastic energy into concentric contraction, the duration of stretching and switch should be shorter or the same as the duration of the life-span of each transversal bridge (30 - 40 milliseconds, in the opposite case the elastic energy is lost (Bosco, 1985).

These finds are also confirmed by the contemporary sprint practice. The model of the sprinting stride technique is directed toward the shortest possible amortisation phase (contact with foot must be performed close to the center-point) and a relatively short active knee phase of the push-off leg which is 25 to 30 degrees (Ballreich, 1986).

Beside the size of the contraction force and its speed (with best sprinters the time a muscle needs

to relax fully is less than 70 ms), the relaxation dynamics of an individual muscle, actively participating in the running stride, is even more significant for sprinting efficiency. A short relaxation period (in best sprinters the value of half of the relaxation time of the leg extensor muscle is less than 35 ms) enables a faster re-introduction of agonists and in this way a higher stride frequency and especially a better co-ordination among individual muscle groups.

The frequency and the length of the stride are significantly correlated with maximal speed of sprinters of all categories with the exception of 11-14 year old male group. This is logical enough, as these are the two basic components that, in the physical sense, generate the results in the maximal locomotor speed and on the basis of which the young sprinters had been indirectly chosen for sprint running. The correlations of both variables point to a both-sided mutual significance, where the result in maximal speed depends on the optimal correlation of both components.

Most probably correlations point to the fact that frequency is not an independent and decisive determinant of speed, but a parameter which is, in greater part, dependent on the factors of the efficiency of the push-off action (contact duration, vertical pressure). Quite evidently, the frequency, by use of a suitable training process, "adapts" to the degree of strength of the strategically most significant muscle groups. We know of examples of "forcing" the frequency during maximal speed training of the sprinters with the support of special methods (downhill running - the Petkovski method, running by pulling the Hammel method, horizontal pull by help of a rubber band - the Vittorio method, the system of horizontal and vertical pull with the help of an electromotor - the Kuznjecov method), but such interventions into the change of proportions between the stride length, push-off pressure and frequency have not been successful (Bosco, 1986).

Stride frequency, especially of young sprinters, should be dealt with in closest relation to other kinematic and dynamic parameters. Apart from the formation of strength of strategically important muscle groups, also the training process should be directed toward perfecting movement structures - movement technique, which enables an efficient transformation of strength into the speed of locomotion in such a way as to get an optimal ratio between stride length and stride frequency.

Relative frequency is an important parameter in which body height is also implied. The variable has, in all four groups, high positive correlation values with the absolute speed. Better results in sprinting can evidently be expected from those individuals who have, next to somewhat above-average body height, also a high frequency.

Contact duration of sprinters is positively correlated with frequency. In duration of contact, frequency as well as efficiency of the push-off action are implied. This is reflected in the magnitude of the kinematic parameter that has, with all sub-samples of sprinters, a general positive correlation with maximal speed. For the transfer of elastic energy from eccentric contraction (forward support phase) into concentric contraction (back support phase) to occur, the stretching of extensors of the push-off leg must be short enough (30% to 40% milliseconds). The phase of forward support (from the placing of the push-off foot on the surface to the vertical position) can only last from 40% to 45% of the complete contact time (Ozolin 1986). Among the 62 subjects of our sample only 3 young male and 1 female sprinters had the duration of contact shorter than 100 milliseconds. Tabachnik (1991) namely states that one of the basic indicators of high sprinting potential of young sprinters is the duration of contact which must be 100 milliseconds or less.

Vertical pressure is the third parameter that has a high positive correlation with maximal speed in all four sub-samples of subjects. Absolute pressure, where body mass of the subject is not taken into account and is an indication of push-off quantity, as well as relative pressure, which considers body mass and is an indicator of push-off quality, are both significant. Correlation is especially high with the absolute vertical pressure in younger boys ( $R = .88$ ) and also in younger girls ( $R = .84$ ). Correlation coefficients of relative ground reaction force with the criterion are lower.

Regarding the correlation of contact duration and vertical pressure, which is negative, we can draw the following rules: Faster runners develop greater surface pressure during shorter duration of contact, which in consequence influences the absolute and the relative stride length. The correlation of surface pressure and stride length is, in all subject groups, highly positive. The production of great surface pressure during a short time interval (90-100 milliseconds) is thus a basic genetic ability that undoubtedly indicates sprinting talent of beginners.

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