Milan Čoh*
Branko Škof*
Otmar Kugovnik*
Aleš Dolenec*
Tomaš Kampmiller**
Eugen Laczo**
Roman Holček**
Peter Šelinger**

KINEMATIC-DYNAMIC CHARACTERISTICS OF MAXIMAL VELOCITY OF YOUNG SPRINTERS

KINEMATIČNO-DINAMIČNE ZNAČILNOSTI NAJVEČJE HITROSTI MLADIH ŠPRINTERJEV

ABSTRACT

Sprinting speed is a complex ability whose physiological base 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-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 kinematical and dynamical parameters with a locomometer. The vertical pressure on the surface was calculated by biomechanical modelling of running steps. We calculated the correlation between maximal sprinting speed and kinematical and dynamical 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.

Key words: sprint, kinematics, dynamics, diagnostics

IZVLEČEK

Namen študije je bil ugotoviti kinematično-dinamične parametre, njihov trend razvoja in vpliv na učinkovitost v maksimalni šprinterski hitrosti pri mladih šprinterjih in šprinterkah starih od 11 do 18 let.

Študija je nastala kot plod sodelovanja laboratorija za biomehaniko Fakultete za šport v Ljubljani in Fakultete za telesno vzgojo in šport (Fakulta telesnej vychovy a sportu) v Bratislavi.

Rezultati študije kažejo, da se pri mladih šprinterjih obeh spolov izrazito spreminja struktura šprinterskega koraka kot posledica dolžine in frekvence korakov, razmerja kontaktno-letnih faz in vertikalnega pritiska na podlago.

Glede na velikost korelacijskih koeficientov so kontaktni časi (R=0.71), relativna frekvenca (R=0.52) in vertikalni pritisk na podlago (R=0.89) najpomembnejši dejavniki uspešnosti mladih šprinterjev.

Ključne besede: šprint, kinematika, dinamika, diagnostika

*Faculty of Sport, Ljubljana, Slovenia
**Faculty of Physical Education and Sport, Bratislava, Slovakia

INTRODUCTION

Maximal sprinting speed, no doubt the most important factor of competitive sprinting efficiency, is mostly dependent on the neuromuscular processes, the 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 development process of the sprinter. The basic problem in the methodics of sport training is without doubt connected with the choice of relevant training methods - forming a suitable and efficient training process. Mastery of an 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).

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

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 with 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-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:

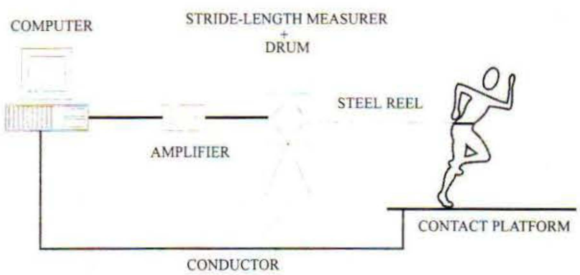
- male sprinters, 11-14 years of age (n=15) (height 162.7 ± 12.6 cm, mass 49.7 ± 12.5 kg)
- male sprinters, 15-18 years of age (n=12) (height 174.8 ± 4.1 cm, mass 66.4 ± 6.6 kg)
- female sprinters, 11-13 years of age (n=15) (height 159.3 ± 9.6 cm, mass 46.2 ± 5.1 kg)
- female sprinters, 14-17 years of age (n=20) (height 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 vychovy a sportu) in Bratislava. The primary instrument used to register kinematic variables was the LOCOMOMETER (Fig. 1), (Kampmiller et al., 1991).

Figure 1:

MEASUREMENT - INSTRUMENT LOCOMOMETER



Variables

The following kinematic variables were used in these 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 a running start (m/s)

The procedure for generating the kinematic variables is based on the functioning of the LOCOMOMETER (authors: T. Kampmiller, E. Laczo, R. Holček, P. Šelinger). It uses a closed circuit (12 V), where the runner pulling a steel reel (diameter 0.005 mm) represents one pole of the circuit. The velocity of the rope is measured by a digital counter which sends impulses via a scanner and amplifier to the computing unit. The second pole of the circuit is the contact platform on which the sprinter runs. This platform was moistened with an electrolyte (sodium chloride – NaCl). The individual touches of the sprinter's shoes on the platform defined the contact and flight phases of the stride, the length and the frequency of the strides were also computed.

In sprint running we proceeded 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 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:

$$D = \frac{2}{g} * Vx * tg\,alpha \qquad (1)$$

where alpha is the flight angle of the centre of gravity

$$Vy = Vx * tg\,alpha \qquad (2)$$

where vy is the vertical component of flight speed

From the above equations we can calculate the speed Vy:

$$Vy = \frac{Dg}{2Vx} \qquad (3)$$

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

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

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

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

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

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

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

Table 1: Kinematic-dynamic parameters of maximal speed for male and female sprinters of different ages ($\bar{X}$: mean value, SD: standard deviation).

Sprinters	MALE					FE MALE				
Age	11-14 n=15		15-18 n=12			11-13 n=15		14-17 n=20		
Parameters	$\bar{X}$	SD	$\bar{X}$	SD		$\bar{X}$	SD	$\bar{X}$	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. vertical pressure	15.88	16.1	18.11	10.5	**	16.97	11.0	17.33	16.9	

** $P<0.01$ * $P<0.05$

TABLE 2: Correlation coeficients of kinematical and dynamical parameters with maximal sprinting speed

Sprinters	MALE				FEMALE			
Parameters	Age: 11–14 n=15		Age: 15–18 n=12		Age: 11–13 n=15		Age: 14–17 n=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. vertical pressure	.58	*	.41		.38		.43	*

* $P<0.05$

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 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 morphologic measures and less as a consequence of differences in the kinematic-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 is 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. Alongside quantitative changes, also structural – or rather the relation between the contact and the flight phases occur with young sprinters. The process of training young sprinters should be oriented precisely into 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 be seen also in parameters of frequency and especially 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 morphologic factors. Body height, or better 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 without doubt 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, where there is a demand for developing as much pressure on the surface as possible. Beside the degree of this pressure, also its frequency of occurrence by contact of feet with the track is 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 with better sprinters the duration of contact is shorter, while the duration of the flight phase is longer. This is just the opposite with poorer 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) a 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 the muscles, this depends on the speed of extension of external pressure and on the number of active transversal bridges. For the occurrence of the transfer of elastic energy into concentric contraction, the duration of stretching and switch should be shorter or the same as the duration of the lifespan of each transversal bridge (30–40 milliseconds), in the opposite case the elastic energy is lost (Bosco, 1985).

These findings 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 fully relax 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 (with best sprinters the value of half of the relaxation time of the leg extensor muscle is less than 35 ms) (Đorđević et al., 1988) 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 years male group. This is logical enough, as these are the two basic components that, in the physical sense, generate the results in the maximal locomotoric 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 Petrovski 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 stride frequency.

Contact duration of sprinters is positively correlated with frequency. In the 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 excentric 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 of younger boys ($R=0.88$) and also of younger girls ($R=0.84$). 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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