CORRELATION OF KINEMATIC AND DYNAMIC CHARACTERISTICS OF THE MAXIMAL VELOCITY SPRINTING STRIDE OF FEMALE SPRINTERS

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INTRODUCTION: Maximal sprinting velocity is defined from the biomechanical viewpoint by stride frequency and stride length. These two factors are correlated and individually conditioned by processes of central regulation of movement. The basic structure of the sprinting stride depends on numerous kinematic and dynamic elements. According to many researches (Ballreich & Kuhlow, 1986; Mero & Komi, 1989; Bruggemann & Glad, 1990; Tidow & Wiemann, 1994; Mero & Komi, 1994; Bosco, Vittori & Matteucci, 1995; Lehmann & Voss, 1997; Viitasalo et al., 1997; Wank, Frick & Schmidtbleicher, 1998) the execution of the contact phase represents one of the most important biomechanical parameters in sprinting stride structure and is defined by the braking phase and the propulsion phase. Till now the authors - as a rule - approached this topic separately from the viewpoint of dynamic and kinematic characteristics.
The purpose of this study was to ascertain the kinematic and dynamic structure of the sprinting stride with a complex measurement procedure and to identify, by using correlation analysis, those parameters that most generate the results in the maximal sprinting velocity of top female sprinters.

METHODS AND PROCEDURES: Seven top female sprinters of the Slovene National Team were included in the experiment. Their average age was 22.3 ± 3.2 years, average height 1.67 ± 0.08 m, average weight 60.3 ± 7.6 kg , average 100 m result 11.91 ± 0.54 s and best 100 m result 11.36 s.
The measurements were performed at a track and field stadium, covered with Tartan turf. Each sprinter executed two runs on a 45 m track at maximal velocity. There was an eight-to-ten minute break between the two runs. The sprinters used spiked shoes. The measurement system consisted of three units: a tensiometric platform, the APAS kinematic system and a system of two pairs of photo-cells for measuring the velocity of the sprinters. To register the dynamic parameters of the sprinting stride, we used the KISTLER 9287 force platform, of size 900 x 600 mm, covered with a Tartan turf and installed in the same plane as the athletic track. On the tensiometric platform we measured forces in the contact phase of the sprinting stride at maximal velocity in three directions: X axis - horizontal direction, Z axis - transversal direction and Y axis - vertical direction. The data sampling frequency of the tensiometric platform was 1000 Hz.
To assess the kinematic parameters of the sprinting stride we used the ARIEL (Ariel Dynamics, Inc., USA) video system for 3-D kinematic analysis. The double sprinting stride was recorded with two Panasonic AG-450EG - SVHS cameras, which were synchronized and used a 50 frames/sec. recording frequency, in the phase when the subject traversed the tensiometric platform. The two cameras were placed at a 90 degree angle to the object.

The velocity of the sprinters was measured with two pairs of photo-cells, placed at a distance of 5 m. The first pair was placed 2.5 m before, and the second 2.5 m after the center of the tensiometric force-plate.
The SPSS package was used for statistical analysis of the gathered dynamic and kinematic parameters. The correlation of the individual parameters with maximal sprinting velocity was assessed with Pearson product-moment correlation coefficients, using 0.05 error levels for statistical significance.

RESULTS AND DISCUSSION: The obtained results (Table 1) show the basic kinematic and dynamic characteristics of the sprinting stride of female sprinters at maximal velocity. The average

Table 1: Kinematic dynamic parameters of the sprinting stride and its correlation with maximal velocity

VARIABLE	UNIT	M	SD	R
Maximal velocity	$m.s.^{-1}$	7.38	0.42	--
Stride length	m	1.84	0.15	-0.14
Angle of leg placement in braking phase	^{o}	76.40	2.75	0.43
Push-off angle	^{o}	66.20	3.63	-0.61*
Horizontal projection of C.G. in braking phase	m	0.22	0.05	-0.46
Horizontal projection of C.G. in prop. phase	m	0.64	0.04	0.37
Horizontal velocity of C.G. in braking phase	$m.s^{-1}$	7.79	0.52	0.60*
Horizontal velocity of C.G. in prop. phase	$m.s^{-1}$	8.04	0.46	0.73*
Height of C.G. in braking phase	m	0.94	0.04	-0.23
Height of C.G. in prop. phase	m	0.95	0.04	-0.33
Distance of action on C.G. in contact phase	m	0.64	0.04	0.37
Velocity of swing leg in braking phase	$m.s^{-1}$	12.62	0.58	0.21
Velocity of swing leg in prop. phase	$m.s^{-1}$	16.24	0.76	0.54*
Angular velocity of thigh in prop. phase	^{o} /s	373.76	103.72	0.56*
Duration of contact	ms	108.00	11.00	-0.61
Duration of flight	ms	144.00	0.01	-0.59*
Duration of braking phase	ms	41.00	8.00	-0.67*
Duration of prop. phase	ms	68.00	6.00	-0.32
Maximal force in X-horizontal axis	N	1160.00	240.86	0.32
Maximal force in Y-vertical axis	N	2127.00	284.24	-0.26
Maximal force in Z-side axis	N	315.00	94.13	-0.29
Force impulse in braking phase	N/s	-10.93	3.01	0.48
Force impulse in propulsion phase	N/s	19.80	1.96	-0.40

Legend: M- arithmetic mean, S- standard deviation, R- correlation with maximal velocity, *- coefficient of correlation is statistically significant $p<0.05$
Note: prop. means propulsion

maximal velocity was 8.06 $m.s^{-1}$ with an average stride length of 1.84 m. The key factor that generates maximal velocity is the execution of the contact phase of the sprinting stride, as has already been established by several authors (Mero & Komi, 1989; Tidow & Wiemann, 1994; Viitasalo et al., 1997) on a sample of male sprinters. The duration of the contact phase is on an average 108 milliseconds and has a statistically significant correlation (R= -0.61) with maximal velocity. However, the duration of the contact phase alone is still not a sufficiently relevant indicator of sprinting stride efficiency, The ratio between the duration of the braking and the propulsion phases is important (Ballreich & Kuhlow, 1986). From the graph of forces in the horizontal axis we can conclude that the braking phase lasts 41 ms and the propulsion phase 68 ms - the ratio is therefore 38% : 62%. The braking phase has, as is evident from Table 1, a statistically significant correlation of R= -0.67 at maximal velocity. The primary criterion of an economic sprinting velocity is the smallest possible force impulse in the braking phase and the largest possible in the propulsion phase (Mero & Komi, 1994). In the propulsion phase the female sprinters develop an impulse which is almost double that in the braking phase. The relation of maximal forces in the horizontal and vertical direction is also, besides the force impulses, important for efficient running. The average maximal vertical force is 2127 N, which is almost 3.5 times the weight of the sprinters. Maximal horizontal force is 1160 N, but the correlation of both with maximal velocity was not statistically significant.

The kinematic characteristics of placing the push-off leg on the surface are of key importance in modeling forces in the contact phase. The shortest possible braking phase and reduction of the braking phase can be achieved by placing the foot of the push-off leg close to the vertical projection of the C.G. on the surface. This distance was 0.22 m for the female sprinters of our sample. This parameter shows a tendency for a statistically significant correlation with maximal velocity. The magnitude of the braking impulse is highly connected to the reduction of velocity of C.G. in this phase. The longer the braking phase, the greater the braking impulse, the more marked is the decrease of the horizontal velocity of C.G. in the contact phase of the sprinting stride. At the beginning of the contact phase, at the time of placement of the push-off leg on the surface, the horizontal velocity of C.G. amounts to 7.80 $m.s^{-1}$, at the end of the contact phase 8.06 $m.s^{-1}$. The drop in velocity is 3.1%, showing a very economical sprinting technique (Lehmann & Voss, 1997). The horizontal velocities of C.G. at the beginning and the end of the contact phase have the highest correlation coefficients (R= 0.60 , R= 0.73) with maximal sprinting velocity, measured by photo-cells in a 5 m zone.

From some studies (Tidow & Weimann, 1994; Lehmann & Voss, 1998) it follows that ensuring high "grabbing" velocity of the leg at the time of placement on the surface is important for efficient sprinting velocity. Two parameters are important here. The first is the velocity of extension of the hip in the contact phase, for which ishio-crural muscles are responsible. For the sprinters in our sample, the angular velocity of hip extension in the contact phase was 373 $^{o}/s$ and is statistically significantly correlated with maximal velocity (R = 0.56). The fastest subject in our sample even managed to achieve 519 $^{o}/s$. According to some data (Ito, 1992; Lehmann & Voss) top male sprinters achieve values between 600 $^{o}/s$ and 800 $^{o}/s$. The second important parameter, ensuring an efficient execution of the contact phase, is the "grabbing" velocity of the foot at the time of placement on the surface - this amounts to 2.38 $m.s^{-1}$ in the vertical direction. While on the subject of finding kinematic parameters ensuring an efficient sprinting stride, we must also mention the horizontal velocity of the foot of the swing leg in the braking and the propulsion phases. In the braking phase this velocity amounts to 12.62 $m.s^{-1}$. This parameter is very important, since the swing leg represents the sole segment in the braking phase which produces propulsive force in the forward direction (Mero & Komi, 1994). At the end of the propulsion phase, the horizontal velocity of the foot of the swing leg is 16.24 $m.s^{-1}$, which is more than double the horizontal velocity of C.G. in the contact phase of the sprinting stride. The correlation coefficient of this kinematic variable with maximal velocity is statistically significant (R = 0.54), which confirms the findings of the study by Lehmann and Voss (1998), who state the important function of the swing leg in the propulsion phase, when it contributes an important part to the push-off impulse.

The results of the study without doubt show that the maximal velocity of top female sprinters depends on a biomechanically economical sprinting stride model, defined by both kinematic as well as dynamic parameters of the contact phase and efficient synchronization of the segments of the action of the push-off and swing leg.

CONCLUSIONS: With a sample of seven top female sprinters of the Slovene National Team we analyzed the kinematic and dynamic structure of the sprinting stride and by using correlation analysis identified those parameters which are statistically significantly correlated with maximal sprinting velocity.

The most important generator of sprinting stride efficiency is the execution of the contact phase, especially the ratio between the breaking and the propulsion parts. To ensure maximal sprinting velocity, the force impulse must be as small as possible in the breaking phase, which is possible through an economical placement of the foot of the push-off leg as close as possible to the vertical projection of the body center of gravity on the surface. This action is conditioned by the angular velocity of the extension of the hips in the contact phase of the sprinting stride.

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