KINEMATIC, KINETIC AND ELECTROMYOGRAPHIC CHARACTERISTICS OF THE SPRINTING STRIDE OF TOP FEMALE SPRINTERS

Milan Čoh, Aleš Dolenec, Bojan Jošt
Faculty of Sport, University of Ljubljana, Slovenia

The main purpose of this study was to find those kinematic, kinetic and electromyographic parameters of the sprinting stride that most affect maximal velocity of top female sprinters. A 20 m flying start test was made with a sample of four female sprinters of the Slovene National team. In addition to maximal velocity, nine kinetic parameters in the contact phase of the sprinting stride were measured. It was found that the most important generators of maximal velocity are: duration of contact phase, duration of braking phase, minimal braking impulse, maximal impulse in propulsion phase, preserving maximal horizontal velocity of CG in braking phase and maximal grabbing velocity of the foot in the forward contact phase. In light of the EMG activation, m. biceps femoris is one of the most important muscles in the sprint.

KEY WORDS: maximal sprinting velocity, kinematics, kinetics, electromyography, females

INTRODUCTION: The result in a sprint is generated by many biomechanical factors. According to the studies of Mero and Komi (1987), Bruggeman and Glad (1990), Mero, Komi & Gregor (1992), Mero and Komi (1994), Tidow and Wiemann (1994) the most important factors are: start reaction time, technique, electromyographic activity (EMG) of the muscles, production of force, neural factors, muscle structure; and some external factors (i.e., running surface, footwear and weather conditions). The efficiency of sprinting velocity depends on an optimal cooperation of four phases: starting-block phase, starting acceleration phase, maximal (constant) velocity phase and deceleration phase (Mero, Komi, & Gregor, 1992). Maximal velocity, defined by the product of the stride length and the stride rate, is without a doubt one of the most important factors in sprint speed. Stride length and the stride rate are interrelated and dependent on morphologic characteristics, duration of the contact phase, and force production in the braking and the propulsive phases. EMG activity of the leg muscles is, beside force production, also important for economy of sprinting. A common rule has been established that EMG activation of the lower extremities increases with running speed. This is especially true for the EMG activation prior to and during the braking phase in ground contact (Simonsen, Thomsen, & Klausen, 1985; Mero and Korni, 1987).
The purpose of this study was to establish those kinematic and kinetic characteristics of the sprinting stride and EMG parameters of muscle activation that generate maximal velocity in top female sprinters.

METHOD: The experiment included four top female sprinters of the Slovene National team (age = 24.7 ± 4.1 years, height = 1.66 ± 0.04 m, weight = 57.2 ± 2.5 kg, 100 m performance = 11.53 ± 0.22 s and the best result on 100 m = 11.30 s). Each subject performed two runs with maximal velocity over a distance of 45 m. The dynamic parameters of the sprinting stride were registered with a KISTLER 9287 force platform covered with a tartan layer and installed in the same plane as the track. Ground reaction forces were measured in three directions (X-horizontal, Z–lateral and Y–vertical) in the contact phase of the sprinting stride at maximal velocity. A 3D video system was used to assess kinematic parameters (Ariel Dynamics Inc., USA). The double sprinting stride was videotaped in the phase of passing the force-plate with two synchronised SVHS video-cameras operating at 50 Hz. The velocities of the sprinters were measured with two pairs of photocells (measurement system AMES) placed on a 20 m distance. The first pair was placed 10 m before and the second 10 m after the middle of the force platform. A MATLAB (Mathworks Inc., USA) software package was used to analyze the measured forces. EMG was used to monitor the muscle activation during the run. To record the EMG signals, an eight channel telemetric system (BIOTEL 88 – Glonner) was used. The measurements of the electrical muscular activation were made on muscles of the right leg: m. soleus (SOL), m. gastrocnemius (GAS), m. tibialis anterior (TA),

m. vastus lateralis (VL), m. rectus femoris (RF) and m. biceps femoris (BF). Bi-polar silver-silver-chloride (AG-AgCl) electrodes with a diameter of 0.9 cm (Hellige) were used. Statistical analysis was performed with the SPSS statistical package.

RESULTS AND DISCUSSION: Table 1 includes characteristics of the kinematic, kinetic and electromyographic variables for conditions of maximal sprinting velocity for the four subjects.

Table 1 Kinematic, Kinetic and EMG Parameters of the Sprinting Stride

Variables	Subjects				Mean	SD
	BA	BB	HA	PS		
Maximal velocity ($m \cdot s^{-1}$)	9.090	8.810	8.700	8.890	8.873	0.143
Stride length (m)	1,910	1,970	2,010	2,050	1,985	0,052
Stride frequence (Hz)	4,68	4,23	4,21	4,20	4,33	0,20
Angle of leg placement in braking phase (deg)	74,0	71,4	76,4	76,7	74,6	2,1
Push-off angle (deg)	60,0	66,9	66,5	69,8	65,8	3,5
Horizontal projection of CG in braking phase (m)	0,24	0,30	0,22	0,21	0,24	0,03
Horizontal projection of CG in prop. phase (m)	0,49	0,41	0,42	0,49	0,45	0,03
Horizontal velocity of CG in braking phase ($m.s^{-1}$)	9,06	8,91	7,91	8,89	8,69	0,45
Horizontal velocity of CG in prop. phase ($m.s^{-1}$)	9,24	8,94	8,13	8,91	8,80	0,41
Velocity of swing leg in braking phase ($m.s^{-1}$)	14,54	14,38	13,59	13,89	14,10	0,38
Velocity of swing leg in prop. phase ($m.s^{-1}$)	18,54	19,05	17,93	18,76	18,57	0,41
Grabing velocity of the foot (m.s-1)	5,60	6,24	5,51	4,44	5,44	0,64
Angular velocity of thigh in prop. phase ($deg.s^{-1}$)	545,0	493,9	497,8	528,2	516,2	21,2
Contact phase (ms)	99	108	102	95	101	5
Flight phase (ms)	130	135	145	140	137	5
Braking phase (ms)	39	45	39	37	40	3
Propulsion phase (ms)	60	63	63	58	61	2
Maximal force in X-horizontal axis (N)	718	609	988	971	821	162
Maximal force in Y-vertical axis (N)	1791	1938	1812	2157	1924	145
Maximal force in Z-side axis (N)	236	205	286	210	234	32
Force impulse in braking phase (N.s)	-7,480	-9,100	-10,700	-10,210	-9,373	1,237
Force impulse in propulsion phase (N.s)	14,038	15,250	16,700	15,930	15,480	0,978
EMG activity m. tibialis anterior PP (ms)	-200	-118	-98	-200	-154	46,5
EMG activity m. soleus PP (ms)	-40	-94	-127	-92	-88	31,1
EMG activity m. gastrocnemius medialis PP (ms)	-108	-102	-118	-97	-106	7,8
EMG activity m. rectus femoris PP (ms)	-200	-45	-46	-49	-85	66,4
EMG activity m. vastus lateralis PP (ms)	-200	-160	-49	-58	-117	64,9
EMG activity m. biceps femoris PP (ms)	-153	-155	-177	-154	-160	10,0
EMG activity m. tibialis anterior CP (ms)	50	85	85	84	76	15,0
EMG activity m. soleus CP (ms)	95	98	95	90	95	2,9
EMG activity m. gastrocnemius medialis CP (ms)	75	98	88	89	88	8,2
EMG activity m. rectus femoris CP (ms)	85	36	45	27	48	22,2
EMG activity m. vastus lateralis CP (ms)	64	42	54	96	64	20,0
EMG activity m. biceps femoris CP (ms)	102	96	87	107	98	7,4

Some studies (Mann and Sprauge, 1980; Mero and Komi, 1987; Mero, Komi, & Gregor, 1992) point to a significant connection between the execution of the contact phase and maximal sprint velocity. The higher the velocity of the sprinter, the shorter the contact phase. The duration of the contact phase must of course be optimal, since the sprinter needs to develop the greatest possible horizontal force in the propulsive phase – this force namely pushes the sprinter forward. Biomechanics requires the acceleration phase of the stride to be the longest possible, so that the sprinter can develop maximal force. However, this duration is limited with the running velocity and some kinematic characteristics of the sprinting stride – especially the take-off angle. Optimal execution of the contact phase causes a large difference between the impulses in the braking and the propulsive phases. The braking impulse should be the smallest possible, the propulsive impulse the greatest possible. Sprinters in the current study had an average duration of the contact phase of 101 ms. According to Bruggeman and Glad (1990), top sprinters that develop maximal velocity from 10.20 to 11.60 $m \cdot s^{-1}$ have a contact phase between 85 and 95 ms. Subject BA, who achieved the highest maximal velocity of 9.09 $m \cdot s^{-1}$, also had the shortest contact phase (99 ms). The ratio between the duration of the braking phase and the propulsion phase was 40 % : 60 %, which is from the viewpoint of economy (Mero and Komi, 1994) a very good indicator of a rational technique of maximal sprinting velocity. The braking horizontal force and the braking time that define the braking impulse should be as small as possible so that there is the least possible drop in horizontal velocity of CG in the first part of the contact phase. In the current study, the average horizontal velocity decreased for 1.4 % in the braking phase, showing a very economic execution of the sprinting stride. Previous research on sprinters (Mero, Komi & Gregor, 1992) has reported drops in velocity in the braking phase between 3.1 and 4.8 %.

Female sprinters develop in the propulsion phase an average force impulse 1.63 times greater than in the braking phase. The most favourable ratio (1 : 1.75) of the force impulse in the braking phase and the propulsion phase was exhibited by the fastest subject (BA). Vertical forces have much greater values than the horizontal forces in the contact phase. Maximal vertical force varies in female sprinters between 1791 N and 2157 N, representing 3.2 to 3.7 times their body weight. A general tendency exists that both forces in the horizontal as well as in the vertical direction increase with velocity Mero and Komi (1987). Velocity of movement of the swing is an important parameter in the economy of locomotion in sprint running (Tidow and Wiemann, 1994). It is important to ensure a high horizontal velocity of the foot of the swing leg in the contact phase for an efficient sprinting stride and also the greatest possible "grabbing" velocity of the foot in the front support phase. The swing leg (thigh-shank-foot) is the only segment in the braking phase that produces propulsive force in the forward direction. The average horizontal velocity of the foot of the sprinters in the braking phase in the current study was 14.10 ± 0.38 $m \cdot s^{-1}$ and increased in the propulsion phase on an average by 4.47 $m \cdot s^{-1}$. The fastest sprinter (BA) had the highest horizontal velocity (14.54 $m \cdot s^{-1}$) of the foot of the swing leg in the braking phase. It was determined that in the propulsion phase for female sprinters the horizontal velocity of the foot is 2.11 times greater than the horizontal velocity of CG.

One of the key problems of the bio-mechanics of sprinting is how to ensure the most economic phase of the forward support so that the loss in horizontal velocity of CG is the smallest possible. This is possible with a high backward grabbing velocity of the foot under the CG of the body (Lehmann and Voss, 1998). The average grabbing velocity, just before contact in the forward support phase, is 5.45 ± 0.65 $m \cdot s^{-1}$ for female sprinters. A high grabbing velocity in ensured by the back-swing-velocity generated mostly by the isciocrural muscles (Tidow and Weimann, 1994). Top sprinters manage to achieve an angular back-swing-velocity of up to 800 °/s. The research of Lehmann and Voss (1998) showed that sprinters, with a maximal sprinting velocity between 10.30 and 10.60 $m \cdot s^{-1}$, achieved maximal angular back-swing-velocities between 500 and 600 °/s. Female sprinters in the current study had an average back-swing-velocity of 516 ± 21.2 °/s. On the basis of the results of the current study, there was a general tendency for female athletes, who have achieved better results in maximal sprinting velocity, to have higher back-swing-velocities.

At maximal sprinting velocity, the electrical activation of the shank muscles begins 120 to 180 ms before the contact of the foot with the ground (Simonsen, Thomsen, & Klausen, 1985). For the current subjects, the electrical activation of the TA muscle began on the average 155 ms before the start of the contact phase. The modulation of the SO and GM muscles was different. The electrical activation of SO began 93 ms before the start of the contact phase and GM 106 ms. These two times are shorter than times reported by others (Dietz, Schmidtbleicher, & Noth, 1979; Simonsen, Thomsen, & Klausen, 1985), but still longer than the electro-mechanic delay. So there is still enough time to increase the stiffness of the muscle to an adequate level. The muscles must be sufficiently stiff at the moment of touchdown. Stiffness of the muscles can be regulated with electrical activation of the muscles. The antagonistic muscles can replace outside forces in the unsupported phase of the stride. It is possible, in this way, with the help of a co-activation of TA as an antagonist

and SO and GM as agonists, to achieve greater electrical activation of the SO and GM muscles and, thus, achieve greater stiffness of SO and GM.
The results of electrical activation of the muscles showed that the electrical activity of the muscles ceases before toe-off, i.e. even before the end of the contact phase. Such results were obtained by Simonsen, Thomsen, & Klausen (1985) for sprinting. They hypothesized that the mechanics of delay was the reason that electrical activation of the muscles ends before the end of the contact phase. Mechanical delay is due to the relaxing time of the muscles. M. adductor pollicis has a half relaxing time of 47.3 ms ± 4.9 ms and about 200 ms to full relaxation (Biglang-Ritchie, Johansson, Lippold and Woods, 1983). For our subjects, electrical activity of most muscles ended a little before toe-off. This is somewhat later than given by Simonsen, Thomsen & Klausen (1985). An exception occurred in the VL; its electrical activity ended as given by the previously cited work. Electrical activity of RF lasted to about half the contact phase. In the contact phase, m. BF was activated the longest and its electrical activity lasted an average 101 ms after touchdown. BF is one of the most important muscles in sprinting as previously stated (Mero and Komi, 1987) and also confirmed in this study.

CONCLUSION: The results of the current study allow the conclusion that the execution of the contact phase is the key generator, which is connected with maximal sprinting velocity. The contact phase should be as short as possible and realised in such a way that there is the least possible reduction in the horizontal velocity of CG in the braking phase. An economic execution of the braking phase depends mostly on the grabbing velocity of the thigh and the foot just before touchdown. In light of this, training should be oriented into developing quick and reactive power and practising the technique of movement with the swing leg in the front support phase. A high grabbing velocity of the swing leg has, as a consequence, a higher stride rate that directly affects the result in sprinting. The function of the shank muscles is especially important. Their electrical activation begins before touchdown. Necessary stiffness of the muscles that must resist the force of the surface in the forward support phase is ensured in this way. According to the EMG results, m.biceps femoris is a very important muscle in the biomechanics of sprinting. Its activity in the contact phase lasts longest of all the monitored muscles. Its main role in the forward support phase is to ensure the greatest possible grabbing velocity of the leg in the sprinting stride.

REFERENCES:

Bigland-Ritchie B., Johansson R., Lippold O. C. J., Woods J. J. (1983). Contractile speed and EMG changes during fatigue of sustained maximal voluntary contactions. *Neurophysiology*, 50, 313-337.
Bruggemann, G.P. & Glad, B. (1990). Time analysis of the sprint events. Scinetific research project at the games of the XXXIV Olympiad -Seoul 1988 – final report. New Studies in Athletics, suppl.
Dietz, V., Schmidtbleicher, D., & Noth, J. (1979). Neuronal mechanisms of human locomotion. Journal of Neurophysiology, 42, 1212- 1222.
Lehmann, F., & Voss, G. (1997). Innovationen fur den Sprint und Sprung: "ziehende" Gestaltung der Stützphasen - Tiel 1. *Leistungssport*, **6**, 20-25.
Mero, A., & Komi, P.V. (1987). Electromyographic activity in sprinting at speeds ranging from sub-maximal to supra-maximal. Medicine and Science in *Sports* Exercise, **19**(3), 266-274.
Mero, A., Komi, P.V. & Gregor, R.J. (1992). Biomechanics of Sprint Running. Sporf Medicine, **13**(6), 376-392.
Mero, A., & Komi, P.V. (1994). EMG, Force, and Power Analysis of Sprint-Specific Strength Exercises. Journal of Applied Biomechanics, **10**(1), 1-13.
Simonsen, E., Thomsen, L., & Klausen, K. (1985). Activity of mono – and biarticular leg muscles during sprint running. European Journal of Applied Physiology, 54, 524-532.
Tidow, G., & Wiemann, K. (1994). Zur Optimierung des Sprintlaufs-bewegungs Analytische Aspekte. *Leistungssport*, 5, 14-19.