KINEMATIC AND DYNAMIC ANALYSIS OF HURDLE CLEARANCE TECHNIQUE

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The objective of this study was to establish and analyse those kinematic and dynamic parameters that define an efficient hurdle clearance technique. This is one of the most important factors affecting the performance of athletes in the 110m hurdle event. Test runs from starting blocks with the clearance of five hurdles, set in accordance with the competition rules, were carried out on a sample of four male hurdlers, members of Slovene National Team. Kinematic analysis was performed with a 3D Ariel video system. The dynamic parameters of the take-off and landing of hurdle clearance were determined with a Kistler force platform. It was found that efficient hurdle clearance technique is generated by the following factors: The contact time of take-off, an optimal ratio of the braking phase to propulsion phase of take-off, the ratio of the point of take-off to landing, (relative to the hurdle), flight time, short braking phase in landing, high position of the centre of gravity (CG) at landing and minimal reduction in the horizontal force of the CG at landing.

KEYWORDS: hurdles, technique, kinematics, dynamics

INTRODUCTION: Technically, the high hurdles are among the most demanding track and field events. According to some of the research carried out to date (Schluter, 1981; Mero and Luhtanen, 1986; La Fortune, 1988; McDonald and Dapena, 1991; Dapena, 1991; McLean, 1994; Kampmiller, Slamka and Vanderka, 1999), the hurdle clearance technique is one of the key elements defining the competitive result. From the aspect of biomechanics, hurdles are a combination of cyclic sprinting and acyclic clearance of ten 1.067m hurdles. Therefore, the athlete must possess a high level of sprinting abilities, special flexibility at the hip joint, fast strength, and a high level of technical knowledge. While clearing the hurdle, the loss of horizontal velocity must be as small as possible. However, this depends on numerous factors, especially those, that define the take-off before hurdle clearance, the trajectory of the movement of the CG, and the landing after hurdle clearance. For efficient hurdle clearance, the point of the take-off and the point of landing of hurdle clearance are important. The correct position of these two points is a prerequisite for an optimal CG flight trajectory and reflects in the flight time, which must be as short as possible (Schluter, 1981; Dapena, 1991). In addition to the correct position, the kinematic-dynamic structure of take-off and landing, which directly affects the velocity of hurdle clearance (La Fortune, 1988; McLean, 1994) is also important. Therefore, the objective of the present study was to determine which parameters generate the most efficient hurdle clearance technique, by combining a 3D kinematic analysis and the method of ground reaction forces measurement.

METHODS: Biomechanical analysis was performed on a sample of four male athletes, members of the Slovene National Team, with an average age of 23.5 $\pm$ 5.06 years, average body height 184.72 $\pm$ 1.53 cm, and with an average weight 80.4 $\pm$ 5.84 kg. The mean result in the 110m hurdles was 14.63 $\pm$ 0.59 s. and the best result was 13.90 s. The measurements were carried out on a track-and-field stadium with a tartan surface. According to the protocol, each athlete performed three runs from starting blocks with the clearance of five hurdles, set at standard race distances from the start. The kinematic and dynamic analysis of the technique was performed at the fourth hurdle. A 3D kinematic system ARIEL (Ariel Dynamics inc., USA) with two mutually synchronised digital cameras SONY DSR-300PK, operating at a frequency of 50 Hz and placed at an angle of 90° with respect to the object filmed, were used to establish the kinematic parameters. The stride before hurdle clearance, the hurdle clearance, and the stride after hurdle clearance were analysed. A force platform KISTLER 9287, covered with a tartan layer and mounted on the same level as the track, was used to measure the ground reaction forces during the take-off and landing of the athlete. The vertical and horizontal ground reaction force data for the take-off and landing were collected at a frequency of 2000 Hz. The technique quality of clearing the fourth hurdle was measured with a set of infra-red photocells, placed at a distance of 5 m before and 5 m after the hurdle.

RESULTS AND DISCUSSION: The results in Table 1 show the basic kinematic and dynamic characteristics of hurdle clearance. The speed of the athletes in the zone of hurdle clearance was 7.54 $\pm$ 0.2 m.s^{-1}.

Table 1 Kinematic and Dynamic Parameters of Hurdle Clearance

Parameters	Unit	Subject A	Subject B	Subject C	Subject D	Mean	SD
Rhythmic Units (Hurdle ±5 m)	m.s^{-1}	7.87	7.35	7.51	7.40	7.54	0.23
Take – off (braking phase)							
Horizontal velocity of CG	m.s^{-1}	8.25	7.45	7.26	7.47	7.61	0.44
Vertical velocity of CG	m.s^{-1}	0.05	-0.02	-0.45	-0.61	-0.26	0.32
Centre of gravity to foot distance	m	0.43	0.44	0.57	0.56	0.50	0.08
Braking time	s	0.079	0.078	0.089	0.083	0.082	0.005
Braking time %	%	59.8	58.2	60.5	58.1	59.15	1.19
Peak horizontal force	N	-1681	-1589	-1798	-1801	1717.25	102.14
Peak vertical force	N	3641	4056	3203	3475	3593.75	357.16
Take – off (propulsion phase)							
Horizontal velocity of CG	m.s^{-1}	7.88	6.88	6.64	7.38	7.20	0.55
Vertical velocity of CG	m.s^{-1}	2.26	2.14	2.41	2.26	2.27	0.11
Centre of gravity to foot distance	m	0.50	0.42	0.43	0.50	0.46	0.04
Push-off angle	^{0}	71.0	72.3	73.2	71.1	71.65	1.37
Foot to hurdle distance	m	2.36	2.27	2.32	2.27	2.31	0.04
Contact time	s	0.132	0.134	0.147	0.143	0.139	0.01
Propulsion time	s	0.053	0.056	0.058	0.060	0.057	0.003
Propulsion time %	%	40.2	41.8	39.5	41.9	40.85	1.19
Flight							
Flight time	s	0.38	0.40	0.40	0.40	0.395	0.01
Height of CG above the hurdle	m	0.33	0.33	0.37	0.32	0.34	0.02
Maximal height CG	m	1.42	1.41	1.45	1.41	1.42	0.02
Landing (braking phase)							
Horizontal velocity of CG	m.s^{-1}	7.65	7.21	7.10	7.39	7.34	0.24
Vertical velocity of CG	m.s^{-1}	-1.72	-1.81	-1.73	-1.53	-1.70	0.12
Height of CG	m	1.25	1.19	1.25	1.23	1.23	0.03
Centre of gravity to foot distance	m	-0.18	-0.14	-0.13	-0.13	-0.15	0.02
Foot to hurdle distance	m	1.28	1.39	1.19	1.42	1.32	0.11
Braking time	s	0.017	0.048	0.014	0.014	0.023	0.017
Braking time %	%	17.4	39.1	11.6	12.3	20.10	12.93
Peak horizontal force	N	-678	-1179	- 824	-8.45	-881.50	211.78
Peak vertical force	N	2867	3304	2477	2569	2804.25	372.43
Landing (propulsion phase)							
Horizontal velocity of CG	m.s^{-1}	7.97	7.32	7.39	7.59	7.57	0.29
Vertical velocity of CG	m.s^{-1}	-1.31	-0.51	-0.77	-0.74	-0.83	0.34
Contact time	s	0.098	0.123	0.121	0.114	0.114	0.01
Propulsion time	s	0.081	0.075	0.107	0.100	0.091	0.02
Propulsion time %	%	82.6	60.9	88.4	87.7	79.90	12.93

During take-off, the horizontal velocity of the CG decreased in the braking phase by 0.41 m.s^{-1}, while at the same time the vertical velocity in the propulsion phase increased to 2.53 m.s^{-1}, which is the consequence of the need to raise the centre of gravity over the hurdle.

The change in the relationship between the horizontal and vertical velocity is associated with the dynamic parameters of take-off. The braking phase lasts 59 %, and the propulsion phase 41 % of the total contact time. The total time of the contact phase of hurdlers in front of the hurdle is 0.139 $\pm$ 0.01 s. Similar values of take-off parameters were established in the study by McLean (1994). In the braking phase, defined with the centre of gravity to foot distance = 0.50 $\pm$ 0.08 m, the hurdlers develop a peak horizontal force of - 1717 $\pm$ 102 N and a peak vertical force of 3593 $\pm$ 357 N, which represents 4.5 times their body weight. Therefore, the primary reason for the reduction in the velocity of centre of gravity is the horizontal vector of the ground reaction force, acting in the direction opposite to the direction of the movement of the hurdler.

An efficient execution of take-off in front of the hurdle has also a direct effect on the efficient trajectory of the movement of the CG, which is expressed in the height and time of the flight of the hurdler. For athletes in the study sample, the flight phase lasts 0.395 $\pm$ 0.01 s. The fastest athlete, (subject A), also has the shortest flight time of 0.38s. In addition to the magnitude and relationship of the forces, which the hurdler develops during take-off, the foot to hurdle distance = 2.31 $\pm$ 0.04 m is important for the definition of an efficient trajectory of the centre of gravity. This distance is an individual trait and is associated with the morphological characteristics of the hurdler and with the take-off angle = 71.6 $\pm$ 1.37°. For these hurdlers, the total length of the stride over one hurdle was 3.64 $\pm$ 0.15 m. The landing occurs at 1.32 $\pm$ 0.11 m from the hurdle. In other studies (La Fortune, 1991; McLean, 1994; Kampmiller, Slamka and Vanderka, 1999), the optimal ratio of the take-off to landing point was 65 % : 35 %. In this study, almost the same result was obtained. The ratio of the take-off to landing was 63.7 % : 36.3 %. For subject B, who had the worst result, this ratio was 62.0 % : 38.0 %. The data determined that the fastest hurdler (subject A), had the largest foot to hurdle distance of 2.36 m (64.9 %). This athlete also had the shortest landing to hurdle distance of 1.28 m (35.1 %), and the smallest take-off angle = 71.0°, the consequence of which is a low position of the centre of gravity over the hurdle (0.33 m) and thus a short duration of the flight phase (0.38 s).

For efficient hurdle clearance technique, the landing phase is equally important. A poor technique in performing this component, characterised by a long contact time and a large percentage of braking time, results in a large loss in horizontal velocity of the hurdler (La Fortune 1988, Dapena, 1991). The landing technique differs significantly from the take-off technique. The braking phase lasts only 20 % of the total contact time, which amounts to 0.114 $\pm$ 0.01 s. This means that the athlete must place the foot directly beneath the body's centre of gravity at landing. For top hurdlers, the braking phase lasts only 9 - 10 % of the contact time (Schluter, 1981; McLean, 1994). The fastest hurdler in the present experiment (subject A) had also the shortest contact time of 0.098 sec and used only 17 % of this time for braking. In the remaining propulsive part of the contact time, the athlete increased the horizontal velocity of the centre of gravity by 0.32 $m.s^{-1}$, which is the highest value among all athletes who participated in the experiment. The hurdler who had the worst time in the zone of hurdle clearance (subject B) had the longest contact time of 0.123 s. and used as much as 39 % of this time for braking.

The peak horizontal force attained by the athletes in this sample in the braking phase is 881 $\pm$ 211.7 N. The peak vertical ground reaction force is 2804 $\pm$ 372.4 N. This data points to a large vertical impact force, which the hurdlers can sustain by correctly placing the fully extended leg. In addition to the correct technique, the ability of the muscular system to resist fast stretching and stiffness as a consequence is important in this case. Stiffness as a neural mechanism of muscle action, depends above all on the pre-activation of the muscles and action of the following reflexes, namely the Miotatic reflex and Golgi tendon reflex (Gollhofer and Kyrolainen, 1991). Short-range elastic stiffness is a biomechanical characteristic of landing, in which an immediate mechanical response of the activated muscle to the eccentric contraction in the braking phase of landing is involved. The criterion of efficiency of the execution of this phase, is the height of the CG in the braking phase, which in this case, is 1.23 $\pm$ 0.03 m. Without question, the height of the CG in the landing phase, depends on the morphological characteristics of the athletes, especially their body height. The best athlete (subject A) , managed to maintain the highest position of the centre of gravity after landing and the largest horizontal velocity of 7.97 $m.s^{-1}$. This was achieved, despite the fact that he is the smallest subject in the experimental sample (BH = 183.4 cm) - The landing phase is the most important factor, as it affects the transition from hurdle clearance into sprinting to the next hurdle. For the athletes in the present sample, the horizontal velocity in the braking phase of landing was 7.34 $\pm$ 0.24 $m.s^{-1}$. This indicates that in the phase of hurdle clearance, the horizontal velocity decreased only by 0.27 $m.s^{-1}$, from which it can be concluded that the efficiency of hurdle clearance technique is high.

CONCLUSION: On the basis of the results of this study, it can be established that the execution of take-off and landing defines the degree of efficiency of hurdle clearance. Undoubtedly, this is an important factor, which determines the competition results of athletes in the 110m hurdles event. The time relationship between the braking phase and propulsion phase is completely different in take-off and landing. The function of take-off is to ensure a suitable transformation of the horizontal velocity of the CG into vertical velocity. The horizontal velocity decreases and the vertical velocity increases, due to the change in the direction of the movement of the CG. In the landing phase, which is one of the most important components of technique, the contact time and the braking phase of the contact time must be as short as possible, in order to maintain the horizontal velocity of the CG while clearing the hurdle. The efficiency of hurdle clearance is also defined by the take-off angle, the correct ratio of the foot to hurdle distance in take-off and landing, flight-time, and the height of the centre of gravity over the hurdle. The results of the study can be utilised for good and objective assessment of hurdling technique, diagnosis of shortcomings, and for the control and modelling of the technical preparation of the athletes.

REFERENCES:

Dapena, J. (1991). Hurdle clearance technique. *Track and Field. Quart. Rev.*, **116**(3), 710-712.

Gollhofer, A., & Kyrolainen, H. (1991). Neuromuscular control of the human leg extensor muscles in jump exercises under various stretch-load conditions. *IJSM*,**12**, 34-40.

Kampmiller, T., Slamka, M., & Vanderka, M. (1999). Comparative biomechanical analysis of 110 m hurdles of Igor Kovač and Peter Nedelicky. *Kinesiologia Slovenica*, **1-2**, 26-30.

La Fortune, M.A. (1991). Biomechanical analysis of 110 m hurdles. *Track and Field News*, **105**, 3355-3365.

McLean, B. (1994). The biomechanics of hurdling: Force plate analysis to assess hurdling technique. *New Studies in Athletics*, **4**, 55-58.

McDonald, C., & Dapena, J. (1991). Linear kinematics of the men's and woman's hurdles races. *Medicine and Science in Sports Exercise,* **23**(12), 1382-1402.

Mero, A., & Luhtanen, P. (1986). Biomechanische Untersuchung des Hurdenlaufs wahrend der Weltmeisterschaften in Helsinki. *Leistungssport*, **1**, 42-43.

Schluter, W. (1981). Kinematische Merkmale der 110-m Hurdentechnik. *Leistungssport*, **2**, 118-127.