KINEMATICAL MODEL OF HURDLE CLEARANCE TECHNIQUE

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The objective of our study was to determine the major kinematic parameters that generate a model of hurdle clearance technique on the 4th hurdle in the 110 metres hurdles. A biomechanic analysis was performed on one of the best hurdlers, a world record holder, Colin Jackson. The analysis of the hurdle clearance technique was made by means of 3D kinematic system ARIEL. The subject of the study was kinematic analysis of the take-off, flight and landing. The results showed that the rational technique of hurdle clearance is defined by the following parameters: horizontal speed of CM (centre of mass) in the moment of take-off, the level of CM in take-off, speed of the swing leg during take-off, take-off angle, time of the flight over a hurdle, level of CM above a hurdle, horizontal speed of CM in the landing phase, level of CM in the landing phase, and contact time in the landing phase.

KEY WORDS: hurdles, technique, model, kinematics.

INTRODUCTION: The high hurdles are among the technically most demanding of track and field events. According to some researches carried out so far (Schluter, 1981; Mero, Luhtanen, 1986; La Fortune, 1988; McDonald; Dapena, 1991; McLean, 1994), the hurdle clearance technique is one of the key elements defining the competition result. From the aspect of biomechanics, hurdles is a combination of cyclic sprinting and acyclic clearance of ten 1.067m hurdles. The hurdler must thus posses a high level of sprinting abilities, special flexibility at the hip joint, fast strength, and a high level of technical knowledge. During clearing the hurdle, the loss of horizontal velocity must be as small as possible; however, this depends on numerous factors, especially those which 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 trajectory of the flight of the CG and reflects in the flight time which must be as short as possible (Schluter, 1981; Dapena, 1991). The main objective of the study was to establish a kinematic model of hurdling technique over the fourth hurdle of Colin Jackson.

Colin Jackson is, uncontestedly, one of the greatest track-and-field athletes in the history of British track-and-field. He holds a World Record in the 110m hurdle event (12.91 - Stuttgart, 1993) and in the 60m hurdle event (7.30 - Sindelfingen, 1994). He has established 10 European Records and 8 Records of the Commonwealth Games. Within the scope of preparation for the European track-and-field championship held in 2002 in Munich, he also took part in the international track-and-field meeting " SLOVENIA 2002", where he won in the 100m hurdles with the time 13.47. Thus, an opportunity to analyse the 110m hurdles technique of this extraordinary hurdler presented itself.

METHODS : Biomechanical measurements were carried out by a group of experts of the Biomechanics Laboratory at the Faculty of Sport in Ljubljana. Kinematic parameters in the section between the fourth and the fifth hurdle were measured with two synchronised cameras (SONY-DSR-300 PK) placed at an angle of 120°. The frequency of the cameras was 50 Hz. For the calculation of the body's centre of gravity, a 15-segment model (Dempster, 1955) and the kinematic program ARIEL (Ariel Dynamics Inc., USA) were used. The competition conditions were optimal: the ambient temperature was 27°, and the wind velocity w = 0.0 m.s-1.

RESULTS AND DISCUSSION: On the basis of the results in Table 1, the following characteristics of a kinematic model of the technique of clearing the 4th hurdle by Colin Jackson (C. J.) can be established:

Table 1 Kinematic parameters of clearing the 4th hurdle (C. Jackson - 110m H 13.47).

Rhythmic Units (Hurdle 4 - 5)	m s^{-1}	8.83
Take – off (braking phase)		
Horizontal velocity of CM	m s^{-1}	8.81
Vertical velocity of CM	m s^{-1}	- 0.43
Velocity resultant of CM	m s^{-1}	8.82
Height of CM	m	0.95
Center of mass to foot distance	m	0.46
Knee swing velocity	m s^{-1}	13.78
Ankle swig velocity	m s^{-1}	15.13
Take – off (propulsion phase)		
Horizontal velocity of CM	m s^{-1}	9.11
Vertical velocity of CM	m s^{-1}	2.35
Velocity resultant of CM	m s^{-1}	9.41
Height of CM	m	1.08
Center of mass to foot distance	m	0.38
Push-off angle	°	72.9
Knee swing velocity	m s^{-1}	10.99
Ankle swig velocity	m s^{-1}	18.22
Take-off distance	m	2.09
Contact time	s	0.100
Flight		
Flight time	s	0.36
Height of CM above the hurdle	m	0.45
Maximal height CM	m	1.44
Maximal velocity over the hurdle	m^{-1}	9.05
Landing (braking phase)		
Horizontal velocity of CM	m s^{-1}	8.77
Vertical velocity of CM	m s^{-1}	-1.02
Velocity resultant of CM	m s^{-1}	8.84
Height of CM	m	1.15
Center of mass to foot distance	m	-0.05
Knee swing velocity	m s^{-1}	12.65
Ankle swig velocity	m s^{-1}	13.16
Landing distance	m	1.58
Landing (propulsion phase)		
Horizontal velocity of CM	m s^{-1}	8.41
Vertical velocity of CM	m s^{-1}	-1.32
Velocity resultant of CM	m s^{-1}	8.53
Center of mass to foot distance	m	0.65
Knee swing velocity	m s^{-1}	- 9.86
Ankle swing velocity	m s^{-1}	- 10.56
Contact time	s	0.08

Efficient hurdle clearance is defined by the length of the stride before hurdle clearance and after hurdle clearance. The total hurdle stride length in C. J. is 3.67 m. The take-off distance is 2.09 m, which represents 56.9 % of the total hurdle stride length. The landing distance is 1.58 m, which is 43.1 % of the total hurdle stride length. This ratio is specific for each hurdler and depends above all on the anthropometric characteristics of the hurdler; on the stride rhythm between the hurdles, and on the push-off angle. According to the studies (La Fortune, 1991; McLean, 1994; Salo and Grimshaw, 1995), the optimal ratio between the take-off point and landing point is 60 % : 40%. We can see that C. J. has a slightly shorter stride before hurdle clearance and a slightly longer after hurdle clearance.

The take-off in front of the hurdle is one of the elements having vital importance for optimal hurdle clearance since it directly defines the trajectory of the movement of the centre of mass (CM). The take-off time of the subject amounts to 100 ms, with the take-off consisting of two phases: the braking phase and the propulsion phase. The braking phase must be as short as possible and depends on the angle of the placement of the take-off leg (in C. J. this angle is 64°). The propulsion phase ends with a push-off angle, which is in our subject 72.9°. These

parameters point to that the take-off leg is actively placed on the ground and the shoulders aggressively pushed towards the hurdle.
The velocity of hurdle clearance depends to a large extent on the execution of take-off, which manifests in the horizontal velocity of the CM. The horizontal velocity of the CM in the braking phase is 8.81 m.s-1, while in the propulsion phase it increases to 9.11 m.s-1, i.e. by 3.3%. We can see that the competitor extremely efficiently accelerates the velocity during take-off. In addition to the horizontal velocity of the CM, an important parameter of take-off is also the vertical velocity, which is 2.35 m.s-1. The horizontal and vertical velocity define the elevation velocity of the CM, which is 9.41 m.s-1 and the elevation angle, which amounts to 14.5°. The relationship between these two parameters of velocity shows that the athlete has the ability of an efficient transition from the running stride into the take-off stride.
The quality of hurdle clearance is directly correlated with the height of the CM in the take-off phase. From the aspect of biomechanics, an efficient hurdle race is the one in which vertical oscillations of the CM are as small as possible (Schluter, 1981; McFarlene, 1994). The athlete must maintain a high position of the CM during take-off. In C. J, the height of the CM at the end of the propulsion phase is 1.08 m, which represents 59.3% of his body height (BH = 1.82 m). The raising of the CM from the braking phase to the propulsion phase amounts to 13 cm. The maximum CM height thus depends on the technique of take-off in front of a hurdle and on the anthropometric characteristics of the flight.
In addition to the above mentioned kinematic parameters, the velocity of hurdle clearance depends also on the velocity of the swing leg during the take-off phase. C. J. attacks the hurdle with his swing leg extremely aggressively. The velocity of the knee swing of the swinging leg amounts to more than 13 m.s-1, while the velocity of the foot of the swinging leg is 18.2 m.s-1, which is more than double horizontal velocity of the CM during take-off.
The criterion of an efficient hurdle clearance technique is the shortest possible time of the flight phase (hurdle clearance time) since the sprinter loses velocity in air (Mero and Luhtanen, 1986; McDonald and Dapena, 1991). The length of the flight of the CM of the athlete is 3.30, the time of the flight phase is 0.36 s. In the finalists of the 110m hurdles at the World Championship in 1997 Athens, the average hurdle clearance time at the fourth hurdle was 0.34 s (Johnson 0.32, Jackson - 0.34, Kovac - 0.34, Schwarthoff - 0.30, Philibert - 0.34, Reese - 0.38, Crear - 0.36). The height of the CM above the hurdle is in direct correlation with the hurdle clearance times (Dapena, 1991). The higher the trajectory of the flight of the CM, the longer is, as a rule, the flight phase. In C. J., this value is 45 cm, which in this concrete case does not point to the most efficient trajectory of the flight of CM over the hurdle. The raising of CM relative to the take-off phase is thus 43 cm, which is probably the result of a relatively short take-off distance.
The landing phase is one of the most important elements of the hurdling technique. This phase has the largest reserve potential for improving the competition result (McLean, 1994). In the landing phase it is necessary to carry out as efficiently as possible the transition from hurdle clearance to running between hurdles. This transition from acyclic movement into cyclic movement requires a high degree of technical knowledge, a high level of motor abilities, such as speed, strength, co-ordination, timing, and balance. In the World Record holder, C. J., the execution of this element is really at the very top level. The contact time in the landing phase lasts only 0.08 s. At landing after clearing the hurdle, the hurdler maintains a high position of the CM (1.15 m), which is above all due to the full extension of the leg in the hips and knee. The CM is exactly above the foot. The foot is in complete plantar flexion, thereby neutralising the ground reaction force that occurs at landing after clearing the hurdle. The ground reaction force at that moment (vertical impact force) is 2400 - 3300N (McLean, 1994). In addition to the correct technique, the ability of the muscular system known as Short Range Elastic Stiffness (Gollhofer and Kyrolainen, 1991) is important in order to enable the hurdler to neutralise such a large ground reaction force at landing after clearing the hurdle. The said ability manifests itself in muscle preactivation and action of the myotactic and Golgi tendon reflex. "Soft" landing of the hurdler after hurdle clearance is indicated by the vertical velocity, which is negative and amounts to only -1.02 m.s-1. The high position of the CM, the direction of the knee of the swinging leg, the bending of the trunk forward (37° relative to the vertical), the timing of the

arms relative to the swinging leg, and a stable balance are those elements which generate the maintenance of the horizontal velocity of the CM after hurdle clearance, which is a prerequisite for an efficient model of running to the next hurdle. The horizontal velocity of the CM in the landing phase is 8.77 m.s-1, which means that in the hurdle clearance phase a reduction in velocity by 0.34 m.s-1, i.e. by 3,7% occurred in the athlete. On the basis of this parameter it can be established that C. J. has a very efficient hurdle clearance technique, enabling him to develop optimal velocities between the hurdles.

CONCLUSION: On the basis of the results obtained by the 3 - D kinematic analysis of the 110m hurdles of the World Record holder Colin Jackson, some most important parameters defining a model of hurdle clearance technique have been found. Analysis covered the clearing of the 4th and 5th hurdle. Efficient hurdle clearance can be defined by the horizontal velocity of the CM during the take-off in front of the hurdle; the height of the CM during the take-off; the velocity of the knee swing of the swinging leg; the flight phase time; the smallest possible loss in the horizontal velocity of the CM during clearing the hurdle; a high position of the CM at landing; a short contact time in the landing phase; and the smallest possible vertical oscillations of the CM, head, shoulders, and hips before, during and after clearing the hurdle.

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