KINEMATIC PARAMETERS OF HURDLE CLEARANCE MOTION IN YOUNG, NOVICE ATHLETES

Flora Panteli[1], Athanasia Smirniotou[1] and Apostolos Theodorou[1]

School of Physical Education and Sport Sciences, National and Kapodistrian University of Athens, Athens, Greece[1]

The purpose of the present study was to assess hurdle kinematics of young athletes when clearing the first two hurdles (0.76 m height) of a simulated hurdle race. Participants run the distance from the starting line to the 2nd hurdle. All trials were video recorded in order to evaluate specific kinematic variables related to hurdle clearance motion. Results revealed that young athletes negotiate the hurdles with lower values of horizontal velocity and hurdle clearance distance parameters, and tend to adopt "a jumping action" over the hurdle compared to the motor pattern of more skilled hurdlers. Horizontal velocity variation affected the technical model of hurdle clearance at the 2nd hurdle, compared to the 1st hurdle, forcing young participants to clear the 2nd hurdle with higher vertical displacement.

KEYWORDS: hurdles, kinematics, young athletes.

INTRODUCTION: Track and field hurdling is a complex and sequential motor skill, consisting of high spatio – temporal demands. Competitive hurdling involves running towards successive hurdles placed at specific distances, adjusted to different age and gender groups. Elite hurdlers run the distance from the starting block to the first hurdle at a maximum speed and on seven or eight steps, takeoff from an undefined takeoff point and clear the hurdle with minimal losses in horizontal velocity, with a flat and fast hurdle stride followed by an effective transfer from the hurdle stride to sprinting (Jarver, 1997). Negotiating the distance to the first hurdle or between hurdles and the height of the hurdle are critical requirements for a young hurdler, who lack technical ability, sufficient strength properties and high sprinting abilities (Jarver, 1997). Hurdling performance depends on the maintenance of a high horizontal velocity during hurdle running. As it appears from biomechanical reports (Pollitt, Walker, Bissas, & Merlino, 2017) elite athletes are able to accelerate until the 3rd or 4th hurdle and to preserve their maximal velocity until the 7th or 8th hurdle, maintaining a lower vertical displacement during hurdle clearance. Efficient hurdle clearance motion depends on takeoff execution in front of the hurdle, center of mass trajectory movement and landing following hurdle clearance (Coh & Iskra, 2012). During hurdle running, kinematic parameters of hurdle clearance change as a result of velocity variation (Iskra & Przednowek, 2016; Salo & Scarborough, 2006). Currently, there is little information about hurdling technical characteristics of novice athletes, in a competitive setting. The purpose of the present study was to compare hurdle motion of young athletes, when clearing the first two hurdles (0.76 m height) during a simulated hurdle race, with the motor pattern of more skilled performers and assess likely differences in hurdle clearance parameters between the 1st and the 2nd hurdle as a result of velocity variation.

METHODS: Thirteen young athletes (age: 13 ± 0.5 years, body height: 1.59 ± 4 cm), with two years of training experience in athletics, participated in the current study. Participants completed 4 times the distance from the starting line (standing start) to the 2nd hurdle, with a 5 min rest between attempts. According to the event's rules for the specific age group, the distance from the starting line to the 1st hurdle is 12 m and the distance between hurdles is 7.5 m. All trials were recorded with two stationary high-speed cameras operating at 300fr/sec (Casio EXF1, Casio Computer Co. Ltd, Shibuya, Japan) recording the last step, takeoff and hurdle clearance stride for the 1st and 2nd hurdle respectively. Best time for clearing the 2nd hurdle was taken into consideration for further analysis. For the extraction of step parameters, 0.05 m × 0.05 m custom reference markers were placed on either side of the lines defining the runway. The placement of the markers formed one-meter zones along the

entire runway. The cameras were set on a fixed tripod 12 m away from the middle of the runway and at a distance of 14 m from the hurdle. Calibration was conducted by placing a 2.5 m x 2.5 m frame with 16 control markers perpendicular to the cameras' axis. The X-axis represented the direction of the runway and Y-axis was vertical and perpendicular to the X-axis. Eighteen anatomical points of the body were manually digitized in each recorded video field. The coordinates of the body center of mass (BCM) were calculated for every field using the anatomical data provided by Dempster (1955). A second-order low-pass Butterworth filter with a cut-off frequency of 6 Hz was selected for smoothing. BCM linear kinematics were extracted for HLS and DLS with a 2D-DLT analysis method using the APAS 2010 (Ariel Dynamics Inc., Trabuco Canyon, CA).
The following kinematic variables related to hurdle clearance motion were analyzed:

- horizontal velocity at touchdown (VXtd, m/sec) in front of the hurdle, at the first instant in which the takeoff foot was in contact with the ground,
- horizontal velocity at takeoff (VXto, m/sec) in front of the hurdle, at the last instant of foot contact on the ground before takeoff,
- loss in horizontal velocity during takeoff (VXloss, m/sec), calculated by subtracting the value of horizontal velocity at touchdown from the value of horizontal velocity at takeoff,
- vertical velocity at takeoff (Vyto, m/sec) in front of the hurdle, at the last instant of foot contact on the ground before takeoff,
- resultant takeoff velocity (Vto, m/sec), calculated by the horizontal and vertical velocities of the athlete's centre of mass at the instant of takeoff with the formula $Vto = \sqrt{VYto^2 + VXto^2}$,
- takeoff angle (Angleto, degrees), calculated by the horizontal and vertical velocity of the athlete's centre of mass at the instant of takeoff with the formula $\theta to = \tan^{-1}\frac{VYto}{VXto}$
- takeoff distance (TOD, cm), defined as the horizontal distance between the takeoff point and the hurdle,
- hurdle clearance distance (HCD, cm), calculated by aggregating takeoff distance and landing distance (the horizontal distance between the takeoff point in front of the hurdle and the landing point after clearing the hurdle),
- hurdle clearance time (time of the flight phase; HCT, sec), defined as the time between the last instant of foot contact at takeoff and the first instant of foot contact at landing after hurdle.

Descriptive statistics were used. Data were examined for normality (Shapiro Wilks test). A parametric Pearson correlation coefficient was used to assess the relationship between hurdle clearance parameters for the 1st and 2nd hurdle respectively. Additionally, paired samples t-test was used in order to examine likely differences in kinematic variables between the two hurdles.

RESULTS: Participants of the current study negotiated the hurdles with lower values of horizontal velocity (VXtd, VXto, Vto) and hurdle clearance distance parameters (TOD, HCD) and with higher values of vertical displacement (VYto, Angleto, HCT) compared to the motor pattern of more skilled hurdlers (Table 1). Significant correlations were found among kinematic variables indicating that takeoff parameters are associated with hurdle clearance motion, even in young, novice athletes (Table 2, 3).

Table 1.Differences in kinematic parameters of hurdle clearance between the 1st and 2nd hurdle.

	Hurdle 1		Hurdle 2		mean diff.	95% conf.interval		p-value
	Mean	SD	Mean	SD				
VXtd	6.73	*0.18*	6.46	*0.24*	0.27	0.14	0.4	*0.001*
VXto	5.74	*0.35*	5.43	*0.4*	0.31	0.13	0.48	*0.002*

VXloss	-1	*0.3*	-1.03	*0.32*	0.04	-0.14	0.22	*0.628*
VYto	3.96	*0.97*	4.38	*0.74*	-0.42	-0.87	0.02	*0.061*
Vto	7.03	*0.55*	7	*0.63*	0.02	-0.22	0.26	*0.842*
Angleto	34.25	*7.14*	38.68	*4.59*	-4.43	-7.91	-0.95	*0.017*
TOD	141.87	*17.2*	148.08	*15.06*	-6.21	-10.66	-1.76	*0.01*
HCD	283.4	*18.55*	267.54	*17.12*	15.86	10.6	21.11	*0.0001*
HCT	0.442	*0.04*	0.453	*0.05*	-0.01	-0.04	0.02	*0.432*

Table 2.Kinematic variables correlations for the 1st hurdle.

	VXtd	**VXto**	**VXloss**	**VYto**	**Vto**	**Angleto**	**TOD**	**HCD**	**HCT**
VXtd	1	0.489	-0.021	0.452	**.696****	0.275	-0.055	**.746****	0.412
VXto	0.489	1	**.862****	-0.228	0.325	-0.479	**.605***	0.225	-0.523
VXloss	-0.021	**.862****	1	-0.524	-0.033	**-.709****	**.725****	-0.176	**-.839****
VYto	0.452	-0.228	-0.524	1	**.841****	**.962****	-0.494	**.738****	**.790****
Vto	**.696****	0.325	-0.033	**.841****	1	**.662***	-0.167	**.825****	0.479
Angleto	0.275	-0.479	**-.709****	**.962****	**.662***	1	**-.601***	**.613***	**.858****
TOD	-0.055	**.605***	**.725****	-0.494	-0.167	**-.601***	1	-0.224	**-.738****
HCD	**.746****	0.225	-0.176	**.738****	**.825****	**.613***	-0.224	1	**.613***
HCT	0.412	-0.523	**-.839****	**.790****	0.479	**.858****	**-.738****	**.613***	1

*. $p<0.05$, **. $p<0.01$

Table 3.Kinematic variables correlations for the 2nd hurdle.

	VXtd	**VXto**	**VXloss**	**VYto**	**Vto**	**angleto**	**TOD**	**HCD**	**HCT**
VXtd	1	**.600***	0	**.642***	**.754****	0.395	0.119	**.558***	-0.16
VXto	**.600***	1	**.800****	0.284	**.694****	-0.172	0.491	**.739****	-0.304
VXloss	0	**.800****	1	-0.127	0.303	-0.511	0.524	0.505	-0.261
VYto	**.642***	0.284	-0.127	1	**.885****	**.891****	-0.009	0.387	0.099
Vto	**.754****	**.694****	0.303	**.885****	1	**.579***	0.231	**.653***	-0.074
angleto	0.395	-0.172	-0.511	**.891****	**.579***	1	-0.241	0.049	0.254
TOD	0.119	0.491	0.524	-0.009	0.231	-0.241	1	-0.091	-0.332
HCD	**.558***	**.739****	0.505	0.387	**.653***	0.049	-0.091	1	0.059
HCT	-0.16	-0.304	-0.261	0.099	-0.074	0.254	-0.332	0.059	1

*. $p<0.05$, **. $p<0.01$

DISCUSSION: Negotiating the distance to the first hurdle or between hurdles and the height of the hurdle are critical requirements for a young hurdler. The horizontal velocity of the centre of mass (CM) during the takeoff in front of the hurdle and its maintenance after hurdle clearance is a prerequisite for an efficient model of running to the next hurdle. Efficient hurdling motion is associated with the execution of takeoff, which defines the trajectory of the movement of the centre of mass. The horizontal and vertical velocity during takeoff defines the resultant takeoff velocity and the takeoff angle, and shows the athlete's ability for an efficient transition from the running step into the takeoff step. A lower trajectory of the centre of mass is related to a shorter time of the flight phase (hurdle clearance time) (Coh, 2003).
Young participants approached the 1st hurdle with a 7-step pattern and the 2nd hurdle with a 3-step pattern. Assessing their hurdling motion, it appears that they are characterized by

limited technical and sprinting ability compared to more skilled performers. They approached both hurdles with lower horizontal velocity compared to more skilled (7.00-7.50 m/sec: Coh & Iskra, 2012; Salo & Grimshaw, 1998) and elite hurdlers (8.5-9.3 m/sec: Coh, 2003; Li, Zhou, Li, & Wang, 2011). While elite hurdlers accelerate the horizontal velocity during takeoff (Coh, 2003), young participants presented a loss of horizontal velocity (1 m/sec) while trying to perform the takeoff step. It is argued that a beginner is usually capable to synchronize only 20% of the movement impulses at takeoff, which makes impossible the execution of a fast and powerful takeoff (Klimmer, 1999). Due to different anthropometric characteristics and strength properties, young athletes performed a shorter hurdle clearance stride compared to more skilled athletes (3.00-3.70 m: Coh, 2003; Coh & Iskra, 2012; Li et al., 2011; Salo & Grimshaw, 1998). Although youngsters took off closer to the hurdle, the takeoff distance is 141.87 cm and 148.08 cm, which represents 50% and 55.5% of the total hurdle clearance distance, for the 1st and 2nd hurdle respectively. These values are close to the optimal ratio of 60:40 between takeoff point and landing point (Coh, 2003). Compared to the motor pattern of elite athletes, young athletes cleared the hurdle with a higher vertical velocity, takeoff angle and hurdle clearance time indicating a trend of “a jumping action” over the hurdle at safe vertical distances (Otsuka, Ito, & Ito, 2010; Otsuka, Otomo, Isaka, Kurihara, & Ito, 2015).
Significant correlations were found among kinematic variables indicating that takeoff parameters are associated with hurdle clearance motion, even in young, novice athletes. Specifically, when approaching both hurdles, hurdle clearance distance found to be highly correlated with the resultant takeoff velocity. Resultant takeoff velocity is also associated with the variables horizontal velocity, vertical velocity at takeoff and takeoff angle. When approaching the 1st hurdle, hurdle clearance time was positively correlated with the vertical velocity at takeoff, takeoff angle and hurdle clearance distance, and negatively correlated with the takeoff distance. The ability to takeoff from a further position from the hurdle is related with a shorter hurdle clearance time. On the contrary, when approaching the 2nd hurdle, due to the significantly lower horizontal velocity compared to the first hurdle, participants negotiated the 2nd hurdle with higher vertical velocity, greater takeoff angle, a shortened hurdle clearance stride and a slightly longer flight phase. Velocity variation during hurdle running affects the technical model of hurdle clearance even in more skilled hurdlers (Salo & Scarborough, 2006).

CONCLUSION: Clearing the hurdle with a quick and fluent speed rhythm and with a flat hurdle stride is a demanding motor skill especially for young, novice athletes. The complicated movement sequence required in hurdling in combination with reduced experience, technical ability, physical height and step length makes difficult for them to repeatedly clear the hurdles with a quick and far-reaching traveling motion (Jarver, 1997) forcing them to adopt “a jumping action” over the hurdle.

REFERENCES

Coh, M. (2003).Biomechanical analysis of Colin Jackson’s hurdle clearance technique.*New Studies in Athletics, 18* (1), 37-45.

Coh, M., &Iskra, J. (2012). Biomechanical studies of 110m hurdle clearance technique. *Sport Science, 5* (1), 10-14.

Dempster, W.T. (1955). Space requirements of the seated operator. WADCTR (55–59). Dayton, Ohio: Wright Patterson Air Force Base.

Iskra, J., &Przednowek, K. (2016). Influence of fatigue in the selected kinematic parameters of hurdle clearance in 400m race – in search of an accurate training test. *Proceedings of the 34th International Conference on Biomechanics in Sports,* (p. 687-690), Tsukuba, Japan.

Jarver, J. (1997). *The Hurdles.Contemporary theory, technique and training*.(3rd edition).Tafnews Press.

Klimmer, H. (1999). A single – stride long jump leads to the hitchkick. *Track Coach, 149*, 4754-4757.

Li, X., Zhou, J., Li, N., & Wang, J. (2011).Comparative biomechanics analysis of hurdle clearance techniques.*Portuguese Journal of Sport Sciences, 11* (Suppl. 2), 307-309.

Otsuka, M., Ito, M., & Ito, A. (2010).Analysis of hurdle running at various inter-hurdle distances in an elementary school PE class.*International Journal of Sport and Health Science, 8*, 35-42.

Otsuka, M., Otomo, S., Isaka, T., Kurihara, T., & Ito, A. (2015). Recommendations for instructional content: relationship of hurdle clearance motion with body height and hurdle running time in 12-14 year old boys. *Journal of Physical Education and Sport, 15*(2), 194-201.

Pollitt, L., Walker, J., Bissas, A., & Merlino, S. (2017). *Biomechanical report for the IAAF World Championships London 2017 110m Hurdles Men's*. Leeds Becket University.

Pollitt, L., Walker, J., Bissas, A., & Merlino, S. (2017). *Biomechanical report for the IAAF World Championships London 2017 100m Hurdles Women's*. Leeds Becket University.

Salo, A., &Grimshaw, P. (1998). An examination of kinematic variability of motion analysis in sprint hurdles. *Journal of Applied Biomechanics, 14*, 211-222.

Salo, A., & Scarborough, S. (2006). Changes in technique within a sprint hurdle running. *Sports Biomechanics, 5*(2), 155-166.