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Kinematic analysis of maximum velocity phase in 100m hurdles: A case study

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Introduction:

Understanding human movement is one of the most important tasks in the field of scientific Research. The human body consists of many segments which move due to muscles contraction, so the biomechanical analysis is one of the most important tools that could help us to understand in details the human motion.

In track and field events, biomechanical analysis is an important tool to evaluate athletic performance, and provide coaches, athletes and researchers with useful data which can help them to develop and achieve a high level of performance.

Hurdles events, especially the high hurdles, are among the most demanding events of track and field. The athlete must possess both (speed of a sprinter combined with a high level of technical ability to clear ten hurdles with a minimum loss of horizontal velocity.[2]

Also, it requires a high potential of motor skill in addition to a high level of technical preparation Which require a specific skill preparation during the entire training process.

Success in hurdles events depends on many factors such as the appropriate morphological characteristics (body height, leg length) and specific motor abilities such as power, speed and speed endurance.[1,12]

As any sprint event, the main goal of the hurdle events is to cover the race distance as fast as possible while clearing ten hurdles. From biomechanical view it consists of three main phases start and acceleration phase, maximum velocity phase and deceleration phase. However, hurdles events has a unique structure that it consists of combination between sprinting and hurdle clearance (the continues transition from cyclic movement to acyclic movement)[1,4]

From technical view both men’s 110 meters hurdles and women’s 100 meters hurdles events include specific characteristics phases determined by the athlete’s position to the hurdle (Brüggemann,1990). From this point of view, the 100m hurdles event consists of the following phases Approach run phase: the first eight steps before the first hurdle. Hurdle unit phase:

Preparatory step, Hurdle step (take-off distance and landing distance), Landing step and Recovery step. Run-in phase: the strides between the last hurdle and the finish line.[3,6]

Success in the women's 100m hurdles depends on the optimal combination and continuous alternation between sprinting (cyclical movement) and hurdle clearance (acyclic movements with a minimum loss of horizontal velocity.[8].Although previous studies suggested that female's 100m hurdles has less technical demands than men's 110 meters Hurdles due to the relatively low barrier height compared to men's 110 meters hurdles,[3,4,6,10] fast hurdle step is a key role in success in women's 100 meters hurdles.

Hurdle clearance is considered to be one of the most important tasks of both women and men's hurdles hurdle race structure, it characterized by many factors such as minimal loss of velocity, a low flight path of the centre of gravity as flat as possible effective transitions from sprinting to hurdle step and the fast transition from hurdle step to sprinting [8] By analysis hurdle step time for each hurdle 0.30 – 0.33 sec[11] for an average woman hurdler (13.50 sec in 100 meter hurdles) it can be concluded that hurdle clearance time has a proximally a percentage of4 – 4.5 % of total race time.

Considering the velocity curve of 100m hurdles we found that horizontal velocity increases fromthe start to the 2nd and 3rd hurdle (acceleration phase) and from the 3rd lo the 6th hurdle(maximum velocity phase). Then, velocity is maintained for a while and decreases from the 6 hurdle to the finish (deceleration phase).[5,7]

Many previous studies have been focused onkinematic analysis of hurdle step of elite men hurdlers [1,4,8,12,9,14,13] and women 100m hurdles [3,4,7,8,11,15] ,or using force plat form to examine ground reaction forces during men's 110 meters hurdles[2,13] The purpose of the presented study is to determine the specific kinematical changes related to hurdle clearance and comparing it with the specific kinematical variables in each phase in the national champion with elite athletes.

Methods:

Subject:

One elite female 100 meter hurdler L A (height 1.65 m, weight 63.5 kg, PB 13.64 sec) who came 16th during the world junior athletics championship in Poland 2016 and Egyptian record holder was recorded in a training session during the preparation to the national championship.

Data collection:

During the training session, and after an appropriate warm up, the subject was asked to run a 60m meter hurdles with maximum effort from block start. Two (2) video cameras 50 f/s (model Panasonic HC-V10) were used to collect kinematic data of hurdle step, the cameras were positioned perpendicular to the 4^{th} and 5^{th} hurdles respectively with a field of view 8 m (to cover hurdle step and both take off and landing steps) a scale 1mx1mx1m was positions in hurdle marks before running to scale kinematic data. The subject was prepared to the testing procedures by attaching 4 body marks on the lead leg (left leg) on the following anatomical

points: Hip joint (the greater trochanter), knee joint (the savage), ankle (lateral malleolus) and forefoot. The kinematic analysis was performed using DARTFISH team pro 4.5 software The hurdle step was divided into 4 times instant (T1: is referred to the instant of touchdown of the take off leg in front of the hurdle, T2: the take off, T3: flight phase and T4: landing phase. The selected kinematic parameters presented in Figure 1, table 1 were subjected to the analysis. Among the parameters there were 9 distance parameters, 10 angular parameters,2 temporal parameters and 5 velocity parameters. Description of those parameters is shown in Table 1(adapted from Krzeszowski et al. 2014

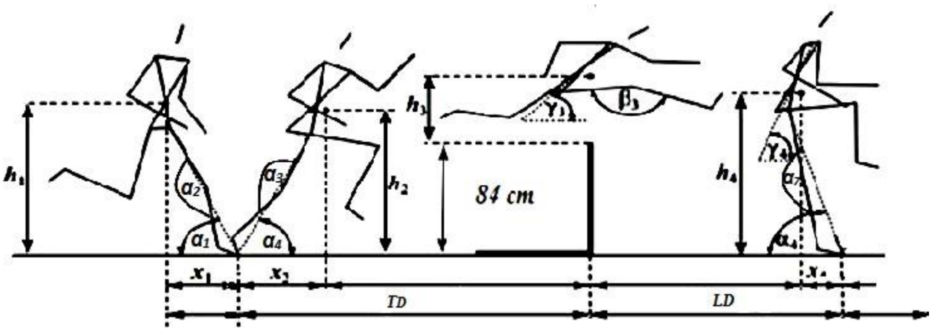

Figure 1: selected kinematic parameters of hurdle step (adapted from Krzeszowski et al. 2014)

T1 Touchdown of the takeoff leg	*T2 : Takeoff phase*
h1 – height of center of gravity at touchdown	*h2 –height of center of gravity at takeoff*
α1 - landing angle of the takeoff leg at touchdown	*α4 – knee angle of trail leg at takeoff*
x1 – horizontal distance between CG and the foot at touchdown	*α5 – takeoff angle*
α2- trail leg Knee angle at touch down	*x2 –horizontal distance between CG and the foot*
α3 –trail leg Knee angle at maximum amortization	*T1- takeoff time*
	TD – takeoff distance to the hurdle
T3 Flight phase	T4 Landing phase
h3 – height of center of gravity over the hurdle	*h4 – height of center of gravity at touch down*
γ3 – trunk angle (attack)	*α6 – landing angle of the lead leg*
β3 – lead leg bending angle	*x4 – horizontal distance between CG and the foot*
T2- flight time	*γ4 – trunk angle (touchdown)*
	α7- knee angle of lead leg at touchdown
	LD – landing distance to the hurdle

Results:

Based on the results of the kinematic analysis ofthe technique of clearing the 4th and 5th hurdle (during maximum velocity phase) the followingfindings can be summarized:

Table 2: Kinematic parameters of touchdown phase

	Unit	Fourth hurdle	Fifth hurdle
h1	m	0.76	0.76
α1	°	60.0	65.0
x1	m	0.33	0.32
α2	°	157	158
α3	°	145	147

Table 3: Kinematic parameters of takeoff phase

	unit	Fourth hurdle	Fifth hurdle
h2	m	0.81	0.83
α4	°	173	170
α5	°	71.0	67.0
x2	m	0.33	0.32
T1	sec	0.13	0.13
TD	m	1.88	1.90

Table 4: Kinematic parameters of flight phase

	unit	Fourth hurdle	Fifth hurdle
h3	m	0.27	0.25
γ3	°	56.0	55.0
β3	°	153	153
T2	sec	0.33	0.33

Table 5: Kinematic parameters of landing phase

	unit	Fourth hurdle	Fifth hurdle
h4	m	0.96	0.96
α6	°	71.0	70.0
x4	m	0.30	0.33
γ4	°	72.0	69.0
α7	°	160	170
LD	m	0.91	0.89

Table 6: CG horizontal velocities during hurdle step

	unit	Fourth hurdle	Fifth hurdle
CG velocity at the touch down in front of the hurdle	m/s	7.20	7.25
CG velocity at the moment of takeoff	m/s	6.6	6.6
CG velocity during flight phase	m/s	6.30	6.4
CG velocity at the moment of touchdown behind the hurdle	m/s	6.15	6.20
Average cm velocity during hurdle step	m/s	6.00	6.12

Discussion:

The main purpose of the present study is to identify the main kinematic variables during the clearance of 4th and 5th hurdle for national champion of 100m hurdles and compare it with kinematic variables of elite level athletes .table 2 shows the values of kinematic variables of the touchdown phase for both 4th and 5th hurdle ,during the touchdown of the takeoff leg in front of the 4th and 5th hurdle CG height was 0.76m and it increases during the takeoff phase about 5 cm during the takeoff of the 4th hurdle and about 7 cm during the takeoff of the 5th hurdle .the increase of CG height between touchdown and takeoff of the trail leg is related to the change in trail leg knee angle during the same phase which is needed to attacking the hurdle and lift the CG with maximum extension in knee joint at the moment of takeoff .the knee angle of the takeoff leg at touchdown in front of the hurdle was 157° and 158° for the 4th and 5th hurdle respectively and it increases at the takeoff to 173° and 170° for the 4th and 5th hurdle respectively .the large decrease of the knee angle of the trail leg during the transition from touchdown to takeoff (157° to 145° in fourth hurdle and 158° to 147° in fifth hurdle) may reflects both poor preparation to takeoff phase that the foot lands far from the CG,and low utilization of elastic power of leg muscles. Milan Coh and Ales Dolonec (1996) suggested that a minimum Flexion at the knee of the take-off leg must be very slight, which results in a minimal loss of horizontal velocity before hurdle clearance.[11]

During touchdown of the trail leg in front of the hurdle, the landing angle of the takeoff leg was 60° and 65° for the 4th and 5th hurdle respectively those values were less than the values of elite level female hurdlers during the same phase (68° – 67° respectively) also, the horizontal distance between CG and the point of touchdown behind the hurdle was 0.33 m and 0.32 m for the 4th and 5th hurdle respectively however those values were larger than the values reported for elite female hurdlers which obtained during the same phase (0.29 m – 0.29 m respectively) that may explain the large landing angle of the takeoff leg the subject places the takeoff foot far from the CG which causes an increase in the takeoff time (0.13 sec) and decrease of horizontal velocity at the moment of takeoff (table 6), Milan Coh and Ales Dolonec (1996) suggested that the effectiveness of the hurdle clearance depends on the good preparation of takeoff phase during the last step before takeoff The hurdler must places the take- off foot actively below the CG so that would decrease the landing distance of takeoff step and decrease the loss of horizontal velocity at the moment of takeoff [11] .

The take-off in front of the hurdle is one of the elements of vital importance to optimal hurdle clearance, since it directly affects and defines the trajectory of the movement of CG over the hurdle and depends on the angle of takeoff [5] Table 2 shows the takeoff angle during the 4th and 5th hurdle, the takeoff angle was 71° – 67° for the 4th and 5th hurdle respectively, those values were less than the values of elite female hurdlers at the same moment (76°–74° respectively)[11] that may explain the low CG height over the hurdle of the research subject (0.27m – 0.25 m) compared with elite female hurdlers (0.36 m – 0.46 m) which presents an advantage for the national champion during clearing the hurdles that may helps her during the transition from hurdle step to sprinting between hurdles , (McFarlane, 2001) suggested that the main factor that affect the transition from hurdle step to sprinting between hurdles is to maintain a closer CG to the natural sprinting path during hurdle clearance, so the hurdler will be able to recover during the landing and recovery step phase [10,15]

The efficient of hurdle clearance depends on the optimal combination between many factors such as takeoff angle, takeoff distance and the active placing of the takeoff foot on the ground[4,5] table 4 shows that trunk incline angle was 56° – 55° for both 4th and

5th hurdle respectively which means that the subject tends to push the shoulders aggressively towards the hurdle early during the takeoff phase, also, the lead leg knee angle was 153° for the 4th and 5th hurdle (Johannes Hucklekemkes 1990) suggested that the straightening of the lead leg should not be stressed during flight phase which would help the hurdler to reach the optimal position during landing and the transition to normal sprinting position [8]also, the knee bent of the lead leg during hurdle clearance plays an important role in decreasing flight time over the hurdle to get back to the ground as fast as possible For efficient hurdle clearance, the point of the take-off and the point of landing after hurdle clearance are very important. Because the correct position of these two points is a prerequisite for an optimal CG flight trajectory during flight phase and affects both trajectory and flight time of CG,(Johannes Hucklekemkes 1990) reported that the optimal takeoff distance to the hurdle for female hurdlers is about 1.90m to 2m to the hurdle[8], in the present study the takeoff distance was 1.88m – 1.90m for the 4 and 5 hurdle respectively those values are less than the values of elite female hurdlers which was 2.16m – 2.09 for the 4th and 5th hurdle respectively [11] however the landing distance for the research subject was 0.91m – 0.89m for 4th and 5th hurdle respectively .those results also are less than the same elite hurdler which the landing distance at the same position was 1.13m-– 1.00m respectively. Although the research subject has less hurdle step length 2.79m compared with the elite female hurdler (3.29m)[4,11] the hurdle step time for the elite female hurdler was less than the research subject (0.30sec compared to the research subject

0.33sec)that may due to the differences of both physical and morphological characteristics between the elite and sub-elite female hurdlers (Milan Coh et al 2000)suggested that both takeoff and landing distance is an individual trait and is related to the morphological characteristics of the hurdler and with the take- off angle[13]. In addition to that, the correct position, the kinematic-dynamic structure of take-off and landing, which directly affects the velocity of hurdle clearance and affects the efficiency of the transition from sprinting to hurdles and vice versa.

Table 5 shows the kinematics of landing phase of the research subject, the height of CG at touchdown was 0.96m for the 4th and 5th hurdle (CG/body height = 0.69), also, the trunk incline angel at the moment of touchdown was 72° – 69° respectively which ensures optimal conditions for an efficient rhythm of strides between the hurdles and maintenance of speed. The position of the CG at the moment of touch- down after the clearance of the 4th and 5th hurdle facilitates a very smooth transition to the sprint between the hurdles.

The knee angle of the lead leg at touch down behind the hurdle was 160° – 170° for the 4th and 5th hurdle respectively which explain the relative height of CG at touchdown, Johannes Hucklekemkes 1990 suggested that a more extended lead leg knee angle after clearing the hurdle is necessary to maintain a high CG position which helps the athlete to get back to normal sprinting conditions after clearing the hurdle with a minimum loss of horizontal velocity [8]

The landing angle of the lead leg behind the hurdle was 71° – 70° for the 4th and 5th hurdle respectively , also the horizontal distance from CG to the foot at the instant of touchdown was 0.30m – 0.31m respectively. Those values was similar to the values of elite female hurdler that the landing angle was 68 but the horizontal distance of CG to the foot at touchdown was 0.29 which means that the elite athlete places the foot of the lead leg down the CG to decrease contact time and maintain the horizontal velocity of CG after hurdle clearance .Milan coh et al 2000 suggested that the landing phase, is one of the key elements of hurdle clearance technique, so the athlete must places the foot of the lead leg behind CG to decrease both contact time and the braking phase in order to maintain the horizontal velocity of the CG while clearing the hurdle.[11,12,13]

Table 5 shows values of CG velocities during different instants of hurdle step,CG horizontal velocity of the subject at the moment of touchdown in front of the hurdle was 7.20 m/s- 7.25 m/s for the 4th and 5th hurdle respectively, then, CG horizontal velocity decreased about 8.3 % - 8.9% during the instant of takeoff respectively, those values were different for the values reported for elite female hurdlers 8.29 m/s – 8.40 m/s and the loss of horizontal velocity was 5.8 %.the percentage of loss in horizontal velocity during the transition to takeoff position was larger than values reported for elite female hurdler (8.3 % - 8.9 % compared to 5.8 % for elite female hurdlers)[11], CG velocity during takeoff depends on many factors such as CG velocity during sprinting between hurdles, minimizing braking phase and landing distance at takeoff step, Also, the optimum execution of hurdle step depends on the aggressive shorting of the last step by placement of takeoff foot as fast as possible under the CG to avoid the loss of horizontal velocity during takeoff[4] that may explain the large loss in horizontal velocity of CG during takeoff that the research subject places the foot of the takeoff leg far from CG (0.32m compared with elite female hurdler 0.29m),During the transition from hurdle clearance to landing, the loss of CG horizontal velocity was 4.5 % - 2.8 % during flight and landing after hurdle clearance respectively, the research subject has a good execution of hurdle clearance with a minimum loss of CG horizontal velocity due to the decrease of CG height over the hurdle (0.25) and an optimal landing angle (71°–70°) that helps her to reach the optimal position to sprinting between hurdles.

Conclusion:

Many of the differences in hurdle clearance technique between elite hurdle and sub-elite female hurdlers analyzed in the present study are fairly small as indicated by the present data such as horizontal distance between CG and foot at the moment of takeoff ,takeoff and landing distance,. However, hurdle clearance velocity is a key role differentiating the race performance among elite female hurdlers This can ensure the importance of achieving high horizontal velocity between the hurdles and maintaining it during the hurdle clearance, also maintaining a relative high CG height during touchdown after hurdle clearance has a major role in maintaining horizontal velocity after clearing the hurdle and fast transition to normal sprinting technique between hurdles this can be achieved by designing efficient drills to minimize takeoff distance of takeoff step and efficient elastic strength training which will result in low takeoff time and low relative knee flexion during takeoff.

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