AN ATTEMPT TO ASSESS THE SELECTED HURDLE STEP KINEMATIC PARAMETERS USING METHODS OF COMPUTER VISION

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Abstract:
The purpose of this study is to assess the selected kinematic parameters of the hurdle step using computer vision methods. In this paper, 13 distance parameters and 7 angular parameters of the hurdle step were presented. The analysis was based on the footage recorded by a CCTV camera. The recording included three races performed by a hurdle runner at a medium training level. The obtained results confirmed the conditions for using computer vision methods in order to support and evaluate the selected parameters of the hurdle clearance technique.

INTRODUCTION

With respect to motor and technical skills, the hurdle races are ranked among complex athletic events. The results in that event depend largely on the level of strength, on the hurdle clearance technique (hurdle step) and the so-called hurdle rhythm [Hyjek 2013; Iskra 2006].

An extensive number of studies concerning the analysis of the kinematic structure of the hurdle race are included in the biomechanical research. In 1994 those studies were divided into three groups; large part of them includes comparative analysis, involving a comparison of the runners' selected kinematic parameters [Girmshaw et al. 1994]. In that event, biomechanical studies focus mostly on the so-called high hurdles (110m), less often on the 400m distance. The analysis of hurdle runs over longer distances entails some technical problems, which are due to different characteristics of the run [Iskra 2006; Iskra 2012].

Hurdling is a frequent object of research; among them, studies using an experimental model of comprehensive and cyclic motor skills [Grimshaw 1995], and analysis of the impact of sports training techniques on the change of the race technique can be distinguished [Iskra 2001]. The research includes also kinetic studies, which are based on the dynamographic method and use specialized equipment for evaluation of dynamic parameters of the hurdle step over the sprint distance [Coh et al. 1998; McLean 1994].

An important part in the examination of kinematic structure of hurdle race plays the selection of research material, i.e. the number of respondents and their sports level as well as the selection of appropriate parameters should be taken into account. Iskra et al. [2001], presented a study on the hurdle clearance technique, in which the research group consisted of specialist hurdlers, decathlon hurdlers and hurdle runners at the academic level. The test parameters were divided into spatial, temporal and spatio-temporal ones [Iskra et al. 2000]. The selection and number of parameters are not standardized, there are studies, in which 67 [Iliew, Primakov 1978] and even 120 parameters were used in order to describe the kinematic structure of the race [Wilimczik 1972].

The kinematics of movement is a tool that is most widely used for assessing the hurdle race technique. While rating the kinematic investigations in the field of hurdle racing, the

range of movement, which includes the so-called hurdle step and the phase of movement from the takeoff position before the hurdle to touchdown behind it should be taken into account. The narrowed analysis of hurdle step is characterized by the simplicity of conducting the investigations and their high accuracy. More difficult is the biomechanical analysis of the longer section of the race, i.e. so called rhythmic unit. It consists of the hurdle step and the running steps performed between the hurdles. That analysis applies most frequently to distances over 100m and 110m hurdles with three steps between the hurdles [Iskra 2012].

An important element of the research is also selection of the measuring equipment. The method and quality of the collected material and its subsequent processing can contribute to measurement errors that may substantially affect the results [Chow 1993].

The main purpose of this study was to evaluate the selected kinematic parameters of hurdle step by using computer vision methods.

MATERIAL

The research was carried out at the premises of Rzeszów University, Faculty of Physical Education, in the multi-purpose hall with bitumen floor surface. The analysis included a hurdler who achieved results at the level of second sport class in 400 m hurdles (56.90 seconds). The test runner was characterized by body height equal to 194 cm and the weight equal to 86 kg. During the test, the sequence of clearing the second hurdle under statutory 110 meters race conditions, (height 1067 mm, distance between hurdles: 9.14 m) was recorded. Recording was performed with Basler Ace ac645-100gc 100 Hz camera. The measuring position with camera orientation is presented in Figure 1.

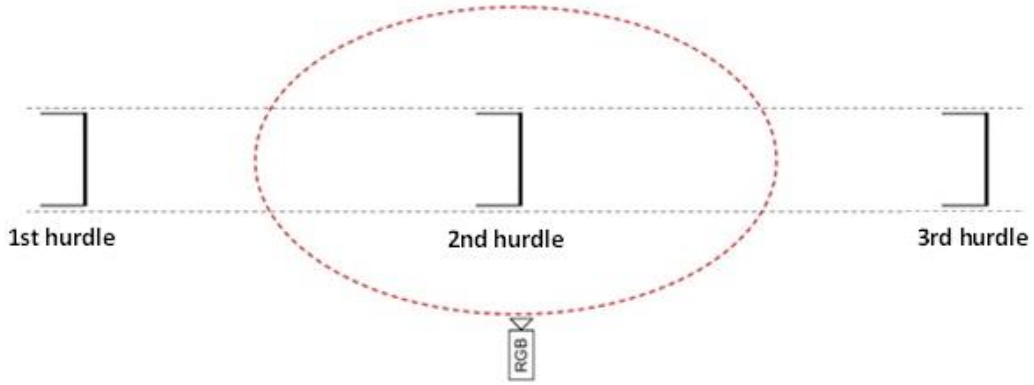

Figure 1. Measuring station

METHODS

The 20 parameters presented in Figure 2 were subjected to the analysis. Among the parameters there were 13 distance parameters and 7 angular parameters. Description of those parameters is shown in Table 1.

In order to estimate the selected kinematic parameters, algorithms of human figure movement tracking based on computer vision methods were used [Krzeszowski et al. 2015] The purpose of tracking is to determine the current position of the human figure, which most accurately reflects the actual situation. It should be noted that the reconstruction of three-dimensional position of human figure based on the analysis of two-dimensional images is a very difficult and complex task in terms of computation [John et al. 2010]. In the process of movement tracking the particle swarm optimization algorithm was used [Kennedy, Ebarhart 1995]; its usefulness in solving problems associated with estimation of the human figure pose has been repeatedly confirmed [Krzeszowski et al. 2012]. In this algorithm, a swarm of particles is used in order to find the best solution, and each particle represents a hypothetical

solution of the problem. In the course of estimation, particles explore the search space and exchange information. The selection of the best solution is carried out based on the value of matching function, which determines the degree of similarity between the searched and estimated human figure pose.

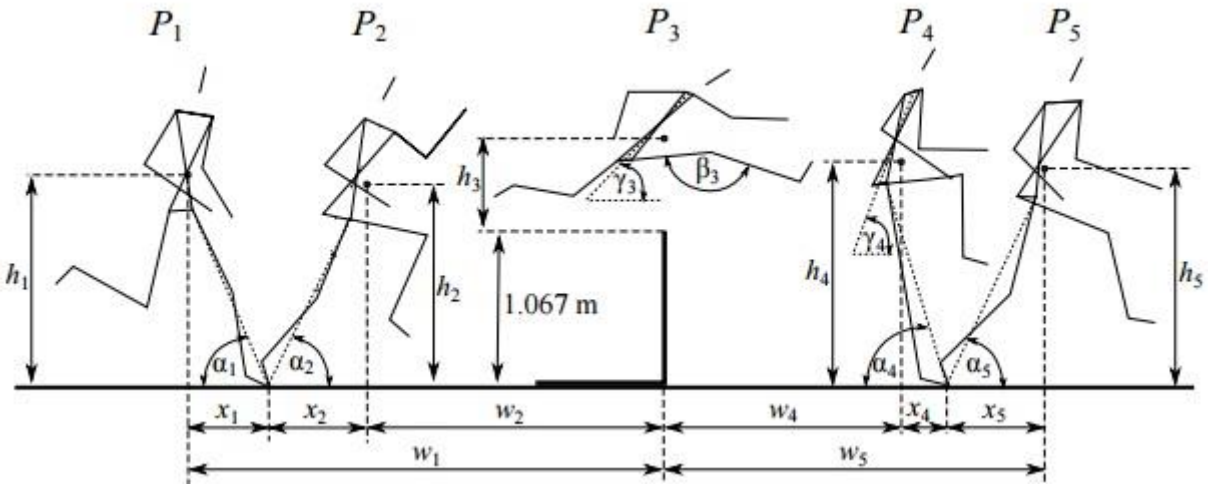

Figure 2. The analyzed parameters hurdle step [Przednowek et al. 2014]

Table 1. Description of estimated kinematic parameters

Phase 1: Taking-off	**Phase 4: Touchdown I**
h_1 – center of gravity height	h_4 – center of gravity height
α_1 – angle of the trail leg	α_4 – angle of the lead leg
x_1 – distance between the center of gravity and the foot	x_4 – distance between the center of gravity and the foot
w_1 – distance between the center of gravity and the hurdle	w_4 – distance between the center of gravity and the hurdle
Phase 2: Attacking the hurdle	γ_4 – trunk angle (touchdown)
h_2 – center of gravity height	**Phase 5: Touchdown II**
α_2 – angle of the trail leg	h_5 – center of gravity height
w_2 – distance between the center of gravity and the hurdle	α_5 – angle of the lead leg
x_2 – distance between the center of gravity and the foot	x_5 – distance between the center of gravity and the foot
Phase 3: Transition – over the hurdle	w_5 – distance between the center of gravity and the hurdle
h_3 – center of gravity height over the hurdle	
γ_3 – trunk angle (attack)	
β_3 – lead leg bending angle	

The accuracy of the proposed method in terms of hurdle step analysis, was verified and reported in the work of Przednowek et al. [2014].

RESULTS AND DISCUSSION

We analyzed the length of each hurdle step and coefficients of ratios between the takeoff and touchdown distances in the conducted racing attempts. The length and the said hurdle step ratio were determined from the following formulas:

$$d = x_2 + w_2 + x_4 + w_4$$

$$w = \frac{x_2+w_2}{x_4+w_4}.$$

From the obtained results it follows that the longest hurdle step was recorded in the first race and its length was approx. 4,41 m. The second race featured in contrast the shortest length of slightly over 4 m. In addition to that, the coefficient w determining the ratio between the takeoff and touchdown distance from the hurdle was analyzed. The obtained values indicate that only the first race featured a longer takeoff length in respect to the touchdown distance. In other races however, a different trend was observed.

Table 2. Hurdle step length in the individual trials (races)

Parameter	Race 1	Race 2	Race 3
Lenght hurdle step - d	4407.6 mm	4011.8 mm	4172.9 mm
Ratio between the takeoff and touchdown distance - w	0.8	1.4	1.2

Figure 3 presents the results of tracking the runner performing the first phase of the hurdle step in three different races. Individual kinematic parameters were presented in Table 3. As it follows from the conducted analysis, during the third race the highest center of gravity height was recorded, while the lowest center of gravity height was observed during the second race. In earlier studies, for advanced hurdlers, the center of gravity height was 950 mm [Coh 2003]. The obtained result confirms the runner's good performance level. The trail leg bending angle was at the similar level in all three races and averaged to approx. 68°. According to other authors, for advanced hurdle racers, that parameter should be approx. 64° [Coh 2003]. The obtained result is comparable to the parameters of runners presenting high sports level.

Significant is differentiation of the distance parameter x_1 determining the distance between the foot and the center of gravity; its highest value was observed in the third race and the lowest in second race. In both races, the difference of distance values was approx. 140 mm. The last parameter analyzed in phase 1, was the parameter describing the distance between the center of gravity and the hurdle, which is a significant component of the hurdle step length. The shortest distance to the hurdle was recorded in the first race, while in the second and third races similar values within the range of approx. 2750 mm were noted. As demonstrated in earlier studies, the correct distance between the center of gravity and the hurdle is 2560 mm [Coh 2003]. The obtained result is close to the result obtained by the world-class hurdle runner, Colin Jackson.

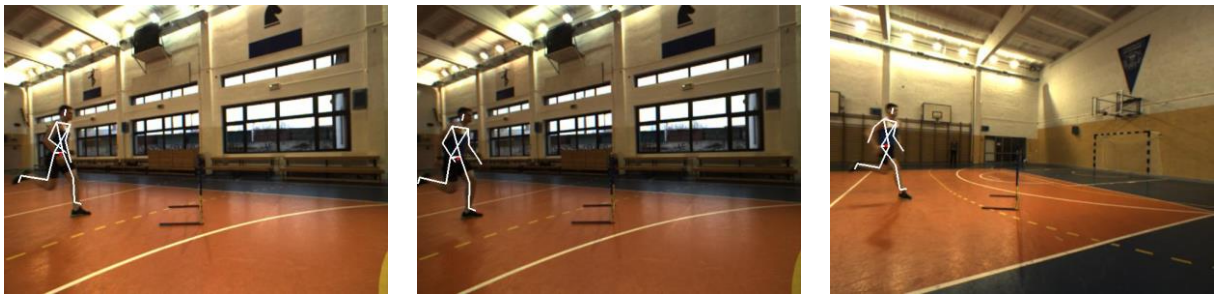

Figure 3. Tracking Phase 1; a) race 1, b) race 2, c) race 3

Table 3. Numerical characteristics of kinematic parameters for Phase 1 hurdle step

Phase 1 – Taking-off					
Parameter		h_1 [mm]	α_1 [°]	x_1 [mm]	w_1[mm]
Race 1	$\bar{x}$	1006.2	68	211.4	-2484.4
	sd	29.1	3.4	51.8	11.7
Race 2	$\bar{x}$	985.4	72.8	133.8	-2740.7
	sd	22.9	3.5	42.3	22.5
Race 3	$\bar{x}$	1184.5	62.8	277.7	-2756.7
	sd	42.2	7.1	167.4	43.6
Average for 3 races		**1058.7**	**67.8**	**207.6**	**-2660.6**

Figure 4 presents the results of tracking the runner performing the second phase of the hurdle step in three different races. Individual kinematic parameters of that phase are presented in Table 4. As is follows from the conducted analysis, the highest center of gravity height was recorded during the third race, while the lowest center of gravity height was observed during the first race. According to previous studies, for advanced hurdlers that parameter should be 1080 mm [Coh 2003]. It turns also out that in terms of this parameter, the first attempt was the best.

The trail leg bending angle during the hurdle attack was at the similar level in all three races and averaged to approx. 78°. The previous studies have shown that the trail leg bending angle during the hurdle attack should be approx. 73° [Coh 2003]. The resulting angular parameter in phase 2 indicates a good control of movement technique. The next parameter analyzed in phase 2 was the parameter describing the distance between the center of gravity and the hurdle, which is part of the hurdle step length. The shortest distance to the hurdle was recorded in the first race, while in the second and third races similar values within the range of about 1800 mm were noted.

According to Coh [2003], that parameter should be about 1720 mm. The last parameter analyzed in phase 2, was the distance parameter x_2, describing the distance between the foot and the center of gravity; its highest value was observed in second race and the lowest value was noted in the first race. According to Coh [2003], the correct distance between the foot and the center of gravity should be within the range from 290 mm to 390 mm. The result obtained in the first race confirms the good sports level of the runner.

Figure 4. Tracking Phase 2; a) a first race, b) a second race, c) a third race

Table 4. Numerical characteristics of kinetic parameters for Phase 2 hurdle step

Phase 2 - Attacking the hurdle					
Parameter		h_2[mm]	α_2[°]	w_2[mm]	x_2[mm]
Race 1	$\bar{x}$	1238.8	82.4	1670.2	375.4
	sd	49.4	2.6	33.9	43.6
Race 2	$\bar{x}$	1295.0	76	1879.0	468
	sd	12.4	2.4	8.1	37
Race 3	$\bar{x}$	1322.1	78.1	1853.8	451.9
	sd	56.9	6	40.3	91.6
Average for 3 races		**1285.3**	**78.8**	**1801.0**	**431.8**

Figure 5 presents the results of tracking the runner performing the third phase of the hurdle step in three different races. Individual kinematic parameters are shown in Table 5. The analysis showed that the center of gravity of the runner over the hurdle was at the similar level and amounted on average to 656 mm. According to previous studies, for advanced runners, that parameter should be within the range from 270 mm to 380 mm [Iskra et al. 1996].

Significantly differentiated is the angular parameter γ_3 defining the trunk (attack) angle; its highest value was observed in the second race and the lowest in the third race. The difference in both races was about 10°. As show in the previous studies, the correct technique assumes that the trunk inclination angle over the hurdle should be within the range from 41° to 48° [Przednowek et al. 2014]. The best value of that parameter was obtained in the third attempt.

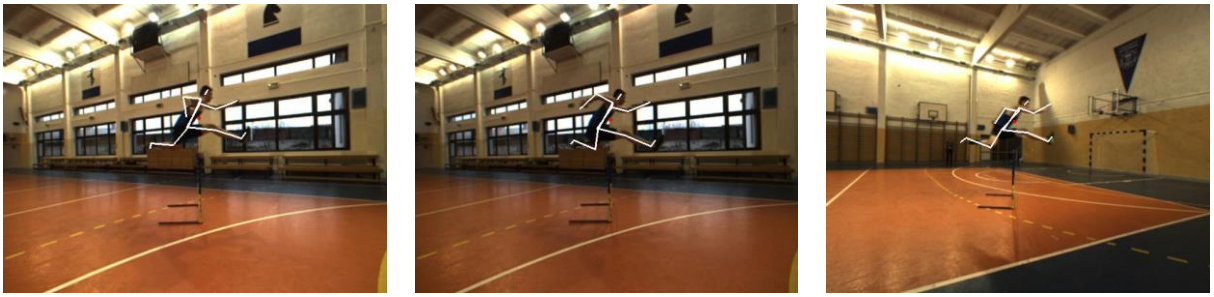

Figure 5. Tracking Phase 3; a) a first race, b) a second race, c) a third race

Table 5. Numerical characteristics of kinetic parameters for Phase 3 hurdle step

Phase 3 – Transition – over the hurdle				
Parameter		h_3[mm]	γ_3[°]	β_3[°]
Race 1	$\bar{x}$	641.4	61.0	161.3
	sd	65.7	6.5	6.6
Race 2	$\bar{x}$	664.9	65.0	161.6
	sd	33.4	8.4	7.0
Race 3	$\bar{x}$	664.1	55.4	164.8
	sd	47.8	2.6	6.2
Average for 3 races		**656.8**	**60.4**	**162.5**

The last parameter analyzed in phase 3 was the parameter describing the lead leg bending angle. All three races featured similar lead leg bending angle that averaged to 162°.

As demonstrated in previous work [Przednowek et al. 2014], the obtained result shows that the hurdler attacked the hurdle with bent leg and did not apply the style known as "drawbar".

Figure 6 presents the results of tracking the runner performing the fourth phase of the hurdle step in three different races. Individual kinematic parameters are shown in Table 6. As is follows from the conducted analysis, the highest center of gravity height was recorded during the second race, while the lowest center of gravity height was observed during the third race. As demonstrated in the previous studies, for advanced hurdle racers, the center of gravity height is about 1150 mm [Coh 2003]. The highest lead leg angular parameter was recorded during the second race, and the third race was characterized by the lowest lead leg angle that averaged to 83°. According to previous studies, for advanced hurdle racers, that parameter should be approx. 80° [Coh 2003]. So it turns out, that in terms of this parameter, the first attempt was the best. Significant is the differentiation of the distance parameter x_4 that determines the distance between the foot and the center of gravity; its highest value was observed in the first race, and the lowest in the second race. The difference between those distances in those two races was 330 mm.

Another analyzed parameter was the distance between the center of gravity and the hurdle (x_4); it had the highest value during the first race, and the lowest value was recorded during the third race. As demonstrated in earlier studies, the correct technique assumes that the distance between the center of gravity and the hurdle should be about 1530 mm [Coh 2003]. The results of the second and third attempt show that they were the best in terms of this parameter. The last analyzed parameter in phase 4 was the parameter describing the trunk angle (touchdown), which was ranked at the similar level and amounted to approx. 66°. It was very similar to the trunk inclination angle during the hurdle attack.

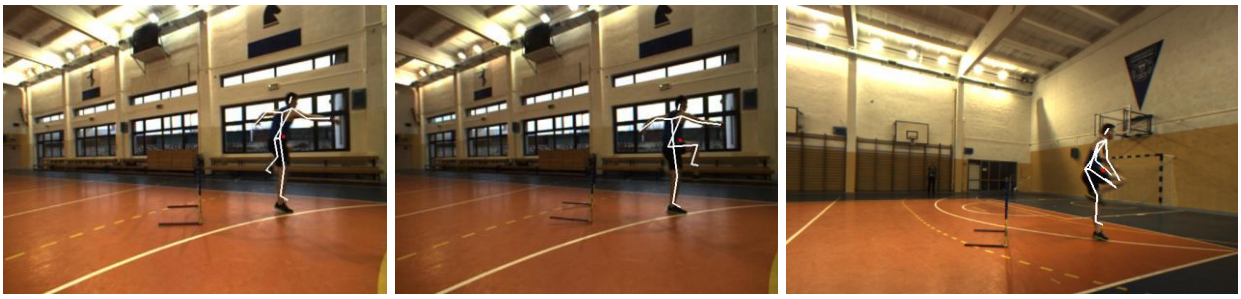

Figure 6. Tracking Phase 4; a) a first race, b) a second race, c) a third race

Table 6. Numerical characteristics of kinetic parameters for Phase 4 hurdle step

Phase 4 – Touchdown I						
Parameter		h_4 [mm]	α_4 [°]	x_4 [mm]	w_4[mm]	γ_3[°]
Race 1	$\bar{x}$	1330.7	77.5	468.4	1893.6	68.4
	sd	26.9	3.6	39.6	16.8	3.6
Race 2	$\bar{x}$	1348.9	102.1	138.4	1526.4	66.9
	sd	20.7	1.8	25.1	9.9	3.0
Race 3	$\bar{x}$	1249.3	71.4	388.3	1478.9	63.6
	sd	23.2	20.5	120.3	17.2	2.9
Average for 3 races		**1309.6**	**83.6**	**331.7**	**1632.9**	**66.3**

Figure 7 presents the results of tracking the fifth phase of the hurdle step in three different races. Individual kinematic parameters are shown in Table 7. As it follows from the conducted analysis, the highest center of gravity height was recorded during the first race, while the lowest center of gravity height was observed during the third race.

According to Coh [2003], for advanced hurdle racers, that parameter is approx. 1060 mm. In terms of this parameter, the third attempt was the best. The lead leg bending angle was ranked at the similar level in all three races and averaged approx. to 73°. According to previous studies, that parameter should be 59° [Coh 2003].

Another parameter analyzed in step 5 was the parameter describing the distance between the center of gravity and the foot. The shortest distance between the center of gravity and the foot was recorded in the second race while the first race featured the longest distance of 561.5 mm. As demonstrated in previous studies, the distance between the center of gravity and the foot should be about 650 mm [Coh 2003]. In terms of this parameter, the first race was most similar.

The last parameter analyzed in the fifth phase is the distance w_5, between the center of gravity and the hurdle; its lowest value was observed in the second race, while in the first and third race similar values within the range of approx. 2080 mm were recorded. The previous studies showed, that the correct distance between the center of gravity and the hurdle should be about 2230 mm [Coh 2003].

Figure 7. Tracking Phase 5; a) a first race, b) a second race, c) a third race

Table 7. Numerical characteristics of kinetic parameters for Phase 5 hurdle step

Phase 5 – Touchdown II					
Parameter		h_5 [mm]	α_5 [°]	x_5 [mm]	w_5[mm]
Race 1	$\bar{x}$	1314.9	67.7	561.5	2080.5
	sd	36.6	2.4	40.7	11.9
Race 2	$\bar{x}$	1266.5	76.0	459.6	1971.6
	sd	18.5	3.1	46.6	26.6
Race 3	$\bar{x}$	1124.6	75.7	468.8	2076.6
	sd	20.6	5.6	86.8	32.7
Average for 3 races		**1235.3**	**73.1**	**496.6**	**2042.9**

CONLUSIONS

In this study, an attempt to evaluate some selected kinematic hurdle step parameters using computer vision methods was made. The analysis carried out in the previous chapter allows for drawing the following conclusions:

- computer vision methods enable measurement and assessment of selected kinematic parameters. Thanks to it one can easily monitor both the progress and impact of applied training measures on the hurdle clearance technique.
- the values of determined parameters confirmed the good sports level of the examined runner. Particularly noteworthy is the repeatability of certain parameters, proving a very good control of the movement technique.

Further work will be focus on developing methods to support estimating kinematic parameters hurdle clearances. Additionally, analysis will be subjected to other elements of the running for 400m hurdles, ie. block star.

REFERENCESS

1. Chow, J. W. (1993). A panning videographic technique to obtain selected kinematic characteristics of the strides in sprint hurdling. Journal of applied Biomechanics, 9(2), 149-159.
2. Čoh, M. (2003). Biomechanical analysis of Colin Jackson's hurdle clearance technique. New studies in athletics 1: 33-40.
3. Coh, M., Kostelic, J., Pintaric, S. (1998). A biomechanical model of the 100 m hurdles of Brigita Bukovec. Track Coach, 142, 4521–4529.
4. Grimshaw, P. (1995). A kinematic analysis of sprint hurdles training strategies (isolation drills) Athletic Coach 29: 4, 24-28.
5. Grimshaw, P., Marar, L., Salo, A., Longden, B., & Vernon, J. (1994). Biomechanical analysis of sprint hurdles. Athletics Coach, 4, 10-12.
6. Hyjek, J. (2013). Czynniki determinujące rytm w biegu przez płotki u osób o różnym poziomie zaawansowania sportowego. AWF Katowice.
7. Iliew, I. & Primakow, J. (1978). Faktornata struktura na technikata w bieganeto na 110 m s priepastwia. Trenorska Misl, 4, 7-13
8. Iskra, J. (2001). Morfologiczne i funkcjonalne uwarunkowania rezultatów w biegach przez płotki. AWF Katowice.
9. Iskra, J. (2006). Lekkoatletyka-Podręcznik dla studentów. AWF Katowice.
10. Iskra, J. (2012). Badania naukowe w biegach przez płotki. AWF Katowice.
11. Iskra, J. (2012). Scientific research in hurdle races. AWF Katowice.
12. Iskra, J., Bacik, B., Król, H. (2000). The effect of specyfic exercises on changes in hurdle technique. W: Current research in motor control, (red. J. Raczek, Z. Waśkiewicz, G. Juras). AWF Katowice; 104-117.
13. Iskra, J., Bacik, B., Król, H.,& Mehlich, R. (1996). Różnice w technice pokonywania płotka w grupie najlepszych zawodników w biegu na 110 m przez płotki. W: Problemy badawcze w lekkoatletyce 1996: 89-96.
14. John, V., Trucco, E., Ivekovic, S. (2010). Markerless human articulated tracking using hierarchical particle swarm optimization. Image and Vision Computing 2010; 28(11): 1530-47.
15. Kennedy, J., Ebarhart, R. (1995). Particle swarm optimization. In Proc. of IEEE Int. Conf. on Neural Networks. Piscataway NJ: IEEE Press 1995; p. 1942-8.
16. Krzeszowski T., Przednowek K., Iskra J., Wiktorowicz K., Monocular Tracking of Human Motion in Evaluation of Hurdle Clearance, Sports Science Research and Technology Support, Communications in Computer and Information Science, Springer, vol. 556, pp. 16-29, 2015.
17. Krzeszowski, T., Kwolek, B., Michalczuk, A., Switonski, A., Josinski, H. (2012). View independent human gait recognition using markerless 3d human motion capture. In: Bolc L., Tadeusiewicz R., Chmielewski L., Wojciechowski K., editors. Computer Vision and Graphics, volume 7594 of Lecture Notes in Computer Science. Berlin: Springer; 2012. p. 491-500 .
18. McLean, B. (1994). The biomechanics of hurdling: Force plate analysis to assess hurdling technique. In ISBS-Conference Proceedings Archive (Vol. 1, No. 1).
19. Przednowek, K., Iskra, J., Krzeszowski, T. (2014). Analiza kroku płotkowego z wykorzystaniem algorytmów wizji komputerowej na przykładzie zawodnika o wysokim poziomie wytrenowania. Polish J Sport Med, 2014; 30(4) 307–313.
20. Przednowek, K., Krzeszowski, T., Iskra, J., Wiktorowicz, K. (2014). Markerless Motion Tracking in Evaluation of Hurdle Clearance Parameters. icSPORTS 2014. Rome. Italy; 10/2014.
21. Wilimczik, K. (1972). Leistungsbestimmende Merkmale der 110-mHürdentechnik. Ein Beitrag zur Bewegungslehre und Trainingslehre der Leibesübungen.