The Use of IMU-based Human Motion Capture to Assess Kinematic Parameters of Specific Exercises Performed by 400 M Hurdlers

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Keywords: 400 M Hurdles, Hurdle Clearance, Kinematic Analysis, Technique Preparation.

Abstract: The 400 m hurdles is a difficult track and field event, in which the hurdle clearing technique is of crucial importance. In this work, we analyse hurdle clearance while performing two specific exercises: marching and running. We evaluated the kinematic parameters (bending angle and movement speed) of the knee joint and movement trajectory (of the thigh and shank) when performing exercises with the left ("stronger") and right ("weaker") lead leg. Two 400 m hurdlers of the Polish National Athletic Team participated in the analysis. The exercises were performed on five 91 cm high hurdles; the third hurdle was filmed using a Motion Capture (Perception Neuron) system with Axis Neuron Pro software consisting of 18 IMU sensors operating at a frequency of 120 Hz. The analysis demonstrated significant difference in the angle parameters of the "stronger" and "weaker" trail leg knee (1), no differences in the movement speed during exercises performed with alternate legs (2) and individual characteristics of movement trajectory in both exercises (3). The results may be used to optimise of the hurdle training process.

1 INTRODUCTION

The hurdles (at sprinting distances – 100/110 m and at a distance of 400 m) is a complex athletic event in which technique and motor preparation are equally important. (Boyd, 2000, McFarlane, 2000).

The technique used to clear hurdles is an important element of preparation for athletes competing in hurdle events (Iskra, 2012b). Research on clearing obstacles concerns not only the typical hurdle distances (100/110 and 400 m), but also the steeplechase (Hunter et al., 2008), clearing high obstacles by fitness enthusiasts (Mauroy et al., 2014) and running through very low obstacles by general population (Austin et al., 1999). The hurdles is a difficult athletic event, in which the technique of clearing standard obstacles at a height (depending on the distance) of 0.84-1.067 m is essential. These events mostly involve the movement of the lower limbs, referred to in the literature as the "lead leg" (the leg first approaching the hurdle) and "trail leg" (the leg opposite the lead leg) – see the Appendix. Thus, the movements of the lower limbs are a basic subject for biomechanical analyses (kinematic and dynamic) in hurdling, as evidenced by numerous scientific publications (Salo, 2002, Coh et al., 2004, Krzeszowski et al., 2015). The evaluation of hurdle technique focuses mainly at the assessment of the individual phases of hurdle clearing (Krzeszowski et al., 2016). These phases constitute a complex form of dynamic movement.

The 400 m hurdles kinematic is difficult to analyse in terms of movement structure. Running the straight parts and the turns, changing the lead leg and unpredictable changes in the manner of hurdle clearing resulting from increasing fatigue demand certain indirect (non-competitive) means for movement analysis.

Researchers have mostly focused on changes in the centre of gravity during hurdles (Przednowek et al., 2016). An important elements in understanding the technique in 400 m hurdles are the specific marching exercises (Iskra, 2008). Kinematic analyses most often concern the competitive conditions and less frequently the specific exercises carried out dur-

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Iskra, J., Pietrzak, M. and Przednowek, K.
The Use of IMU-based Human Motion Capture to Assess Kinematic Parameters of Specific Exercises Performed by 400 M Hurdlers.
DOI: 10.5220/0008363602090216
In *Proceedings of the 7th International Conference on Sport Sciences Research and Technology Support (icSPORTS 2019)*, pages 209-216
ISBN: 978-989-758-383-4

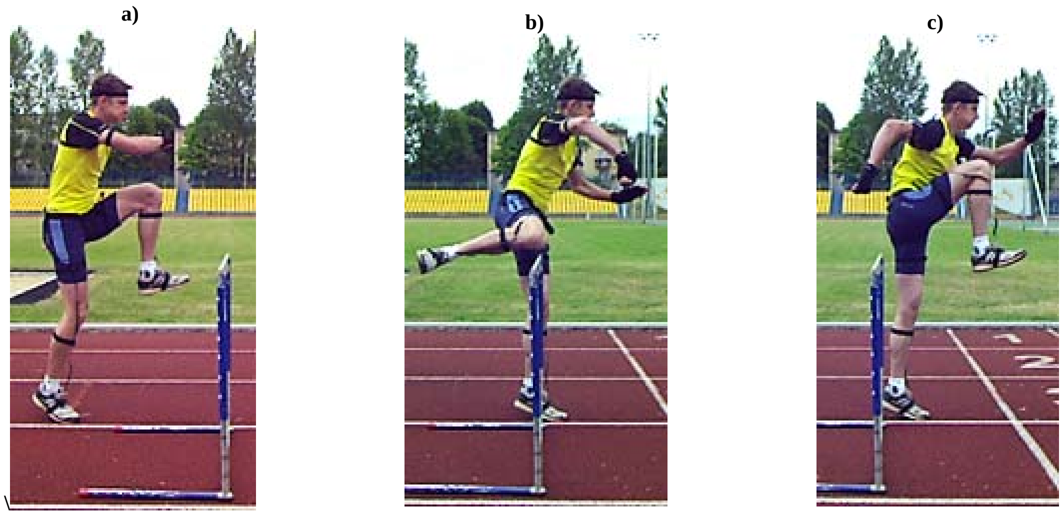

Figure 1: Analyzed moments of overcoming the hurdle in the march.

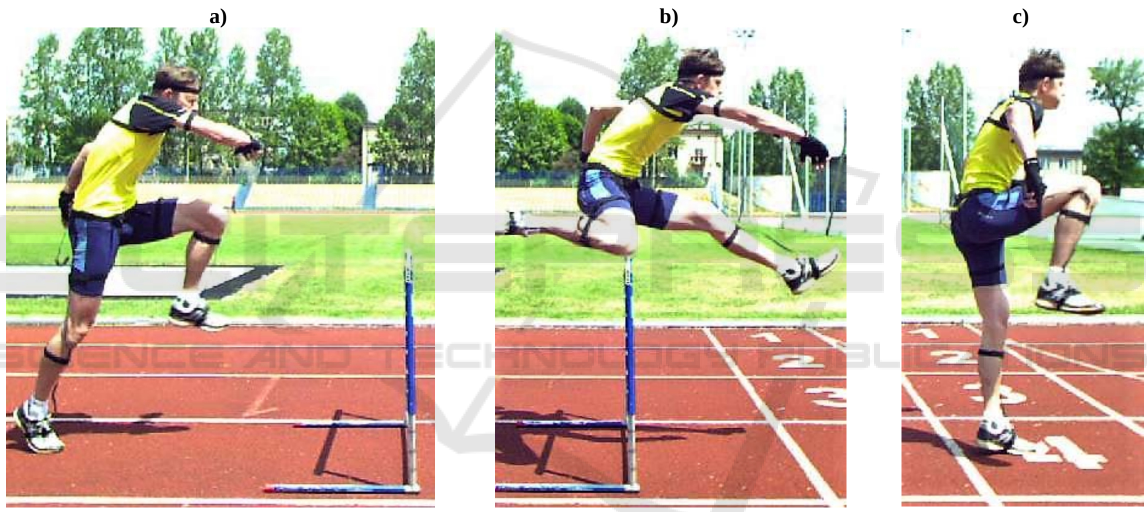

Figure 2: Analyzed moments of overcoming the hurdle on the run.

ing the preparation period (Grimshaw, 1995, Iskra et al., 2000, Przednowek et al., 2016).

The most prominent kinematic analyses concern the running strategy, taking into account the “stride pattern” and “split times” (Guex, 2012). In the current literature on the subject, there are no works dealing with the analysis of the movements performed by 400 m hurdlers during specific exercises taking kinematic measurements into consideration.

The aim of this work is to evaluate the course of movement and selected kinematic parameters, known as the “hurdle step”, performed using the dominant (stronger) and the opposite (weaker) lead leg by highly skilled athletes.

2 MATERIAL AND METHODS

The analysis involved two highly skilled 400 m hurdlers who have competed in the World and European Championships and the Olympic Games.

Both athletes indicated the left leg as their “stronger” lead leg (the one they use more often during a 400 m hurdle race). The basic characteristics of the athletes are presented in Table 1. Written informed consent was obtained from all athletes. The research was conducted according to the guidelines laid down in the Declaration of Helsinki.

Table 1: Study subject characteristics.

	Age [years]	Height [cm]	Weight [kg]	Training experience [years]	Personal best in 400 m hurdles [s]	Stride pattern*	Stronger leg
Athlete 1	26	181	73	10	51.00	7/3	Left
Athlete 2	28	185	80	15	50.84	6/4	Left

* – in the course of a 400 m hurdle race the athlete cleared the hurdles 7 (6) times with the left (= “dominant”) lead leg and 3 (4) times with the right (= “opposite”) lead leg.

The kinematic analysis included specific exercises performed while marching and running. These are basic exercises for hurdle training at any distance, and are used throughout the annual training cycle (Arnold, 1992, McFarlane, 2000, Husbands, 2006). Both athletes made two attempts to march over the hurdles and two attempts to run over the hurdles. Five hurdles were cleared in each of the marching and running exercises, and their movement at the third (middle) hurdle was analysed (filmed). In the marching exercise, the distance between the hurdles was 100 cm, while in the running exercise it was 8.50 m – a distance chosen for specific exercises performed by 400 m hurdlers during technical training by the best coaches (McFarlane, 2000, Iskra, 2012a). In both types of exercise, the first attempt of hurdle clearing was performed with the “stronger” lead leg and the second with the “weaker” one. During the exercise, the competitors were able to clear hurdles with a height of 91 cm (standard height in this event). Both marching attempts were carried out in such a way that the hurdle was cleared with only the trail leg while the lead leg was placed beside the hurdle (trail leg march). This is the most frequently used exercise in hurdle technical training (McFarlane, 2000).

Three essential time points were designated for marching over the hurdle (Figure 1). The first point was the take-off, which is the moment when the athlete performs the take-off in order to clear the hurdle. The second point was the moment when the knee joint of the trail leg was located over the hurdle. The third point was the landing, determined by the moment when the player put the lead leg behind the hurdle and the knee joint of the trail leg was drawn up to the chest. This division of the movement phases in hurdling is consistent with many previous publications (Iskra and Przednowek, 2016, Krzeszowski et al., 2016). Analogous points were determined for the running exercises (Figure 2).

The analysis included the movement of the lower limb, i.e. the thigh and shank, the speed of the point determined by the location of the knee joint and the angle of its bending. These parameters have been particularly emphasized by many authors. The analysis of changes regarding the angle of the knee joint is justified by the frequent use of this parameter in the kinematic structure of the hurdle clearing movement and taking into account the relatively small coefficient of multiple repetition variation over time (Salo and Grimshaw, 1998).

The acquisition of the kinematic parameters was carried out using the inertial Motion Capture system. The Perception Neuron system with AxisNeurono Pro software (Noitom Technology, 2017) was used in the study. The system consisted of 18 IMU sensors operating at 120 Hz. Each sensor included an accelerometer, a gyroscope and a magnetometer. According to the manufacturer, the accuracy of the system is determined by the accuracy of the individual sensors (Static accuracy: Roll:<1 deg, Pitch:<1 deg, Yaw angle:<2 deg). The data were captured wirelessly using a WiFi network. The device was calibrated before each sequence. The analysis was carried out using Matlab software and the BoB Biomechanics package. The data generated by the motion capture system (.calc file with global coordinates xyz of segments) were processed. A script was developed that transformed the data into the common coordinate system and calculate the resultant linear velocities. In addition to the parameter values for individual points, the mean values (M), standard deviation (sd) for the parameter during the entire movement were taken into account in the analysis. The statistical significance of differences between mean values was determined using the U Mann-Whitney test.

3 RESULTS

Analysis of the knee joint bending angle showed significant differences between the “stronger” and “weaker” leg only in the case of the trail leg (Table 2). Angular values (in all phases of movement) were different for exercises performed with the “stronger” and “weaker” lead leg. It should be pointed out that the differences observed in the analysis were of an individual character. During the running exercise, the differences in both subjects (Athlete 1 and Athlete 2) were significant (p<001). During the marching exerci-

Table 2: The knee joint bending angle [º].

Athlete	Athlete 1				Athlete 2			
Leg	Trail		Lead		Trail		Lead	
Side	L	R	L	R	L	R	L	R
Marching								
P1	59	65	139	137	64	75	151	133
P2	157	159	52	69	169	139	43	59
P3	166	152	65	59	172	133	82	70
M	139	144	104	113	146	138	105	104
sd	29	27	46	35	28	19	40	33
D	-5		-9		8		1	
p	0.2699		0.6479		**0.0001***		0.1402	
Running								
P1	71	78	144	145	91	71	160	170
P2	144	157	51	104	152	120	41	83
P3	163	169	85	79	165	116	82	59
M	142	149	83	97	147	113	79	81
sd	23	24	45	46	19	12	39	51
D	-7		-14		34		-2	
p	**0.0021***		0.1049		**0.0001***		0.6651	

P1, P2, P3 – time points; M – mean value; sd – standard deviation; D – difference between left and right leg; p – probability of U Mann-Whitney test; L – left leg; R – right leg.

Table 3: The knee joint speed [m/s].

Athlete	Athlete 1				Athlete 2			
Leg	Trail		Lead		Trail		Lead	
Side	L	R	L	R	L	R	L	R
Marching								
P1	5.3	3.8	0.7	0.9	0.9	1.7	0.7	1.0
P2	0.9	0.3	4.4	5.7	1.1	1.4	4.1	3.9
P3	0.4	1.3	2.7	2.4	0.8	0.6	2.5	3.0
M	1.6	1.9	3.0	2.7	1.6	1.3	2.2	2.2
sd	0.9	1.0	1.5	1.7	1.7	0.8	1.6	1.4
D	-0.3		0.3		0.3		0.0	
p	0.1192		0.2018		0.9663		0.3767	
Running								
P1	5.8	7.5	2.3	1.8	5.0	5.1	1.3	1.7
P2	4.2	4.4	6.1	5.4	3.9	4.2	6.1	2.8
P3	4.8	3.8	5.5	8.2	1.8	3.9	6.2	4.2
M	4.8	4.5	5.7	6.0	3.7	3.8	4.8	4.6
sd	1.5	1.0	2.4	2.5	1.7	0.9	1.3	2.5
D	0.3		-0.3		-0.1		0.2	
p	0.5517		0.3686		0.1131		0.0915	

P1, P2, P3 – time points; M – mean value; sd – standard deviation; D – difference between left and right leg; p – probability of U Mann-Whitney test; L – left leg; R – right leg.

cise, the differences concerned only Athlete 1 ($p<01$).

The analysis did not reveal differences between knee bending of the lead leg in the case of exercises performed using the left and right leg (both while marching and running). Further information on the differences in hurdle clearing was provided by movement trajectory analysis (Figure 3 and 4).

During specific exercises performed while marching the “weaker” leg's thigh movement was ahead of the same movement performed with the “stronger” lead leg. The hurdle was cleared from a farther distance and the movement ended closer to the hurdle. This applied to both athletes.

The movement of the trail leg was more individual – the above mentioned aspect applied only to Athlete 2.

When marching over the hurdle, the shank of the “stronger” leg made the movement more smoothly (“round” on the chart); the movement of the “weaker” limb was more ragged (“peak” on the chart). This applied to both the lead leg and the trail leg.

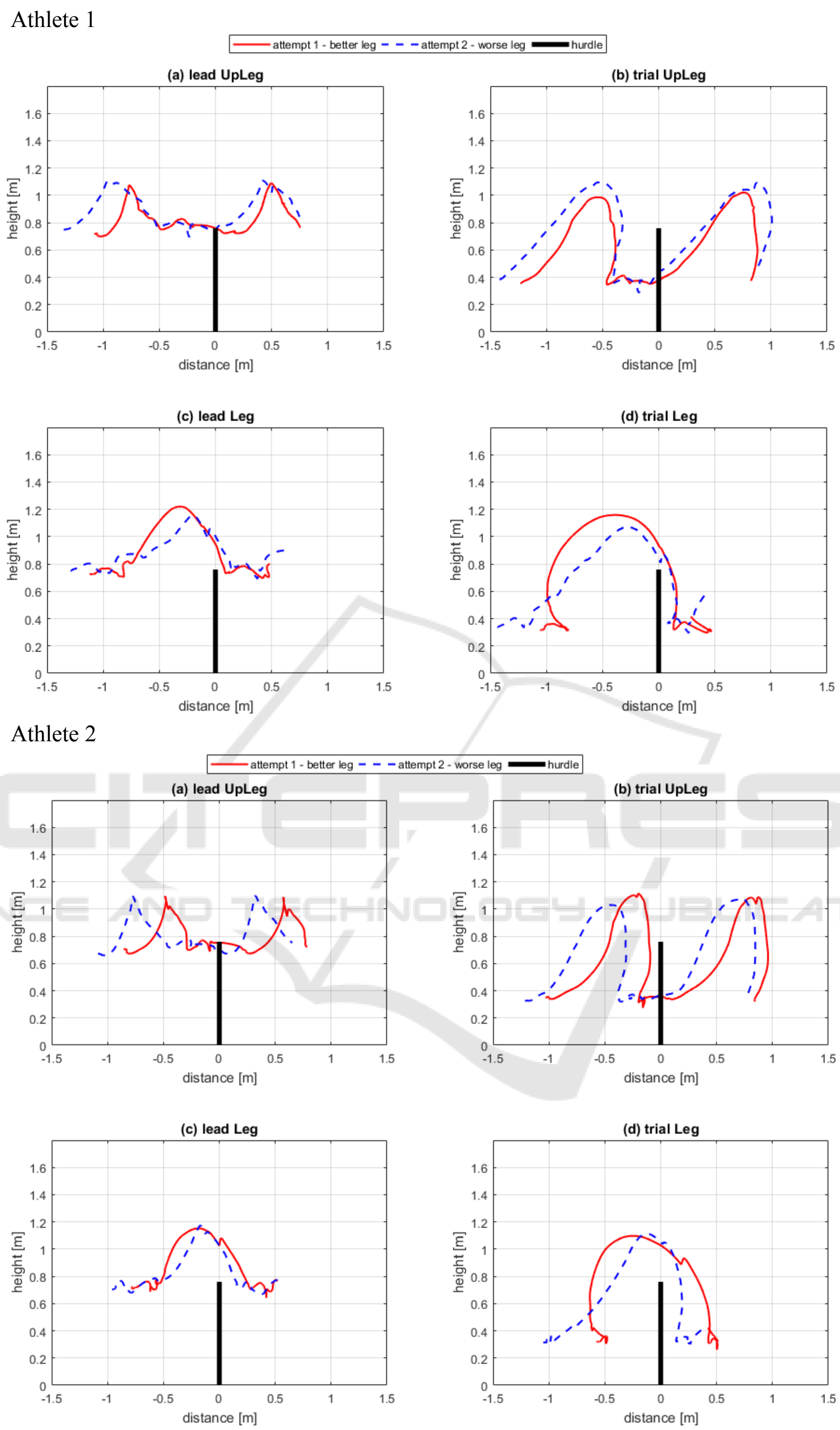

Figure 3: Trajectory of the march (UpLeg – Thigh, Leg – shank).

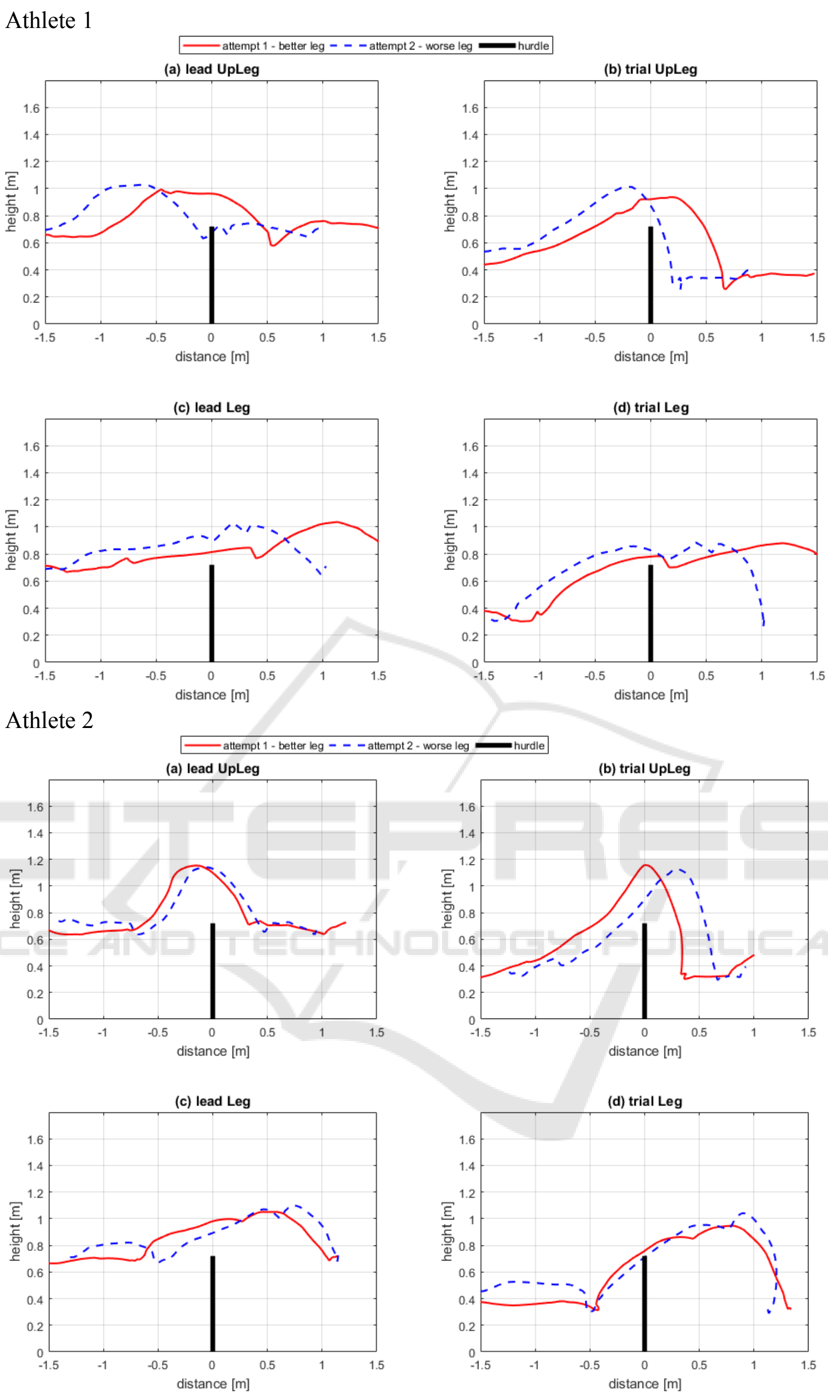

Figure 4: Trajectory of the running (UpLeg – Thigh, Leg – shank).

During specific exercises performed while running, the course of movement while clearing the hurdle was very diverse and individual. In the case of Athlete 1, the movement performed with the "stronger" leg occurred earlier than with the "weaker" leg. In the case of Athlete 2, the situation was reversed. The movement profiles for both athletes were incomparable, which indicated the individual nature of hurdle clearing techniques by the best athletes. The analysis of knee joint speed (resultant) did not show any significant differences between exercises performed with the "stronger" and "weaker" leg (Table 3).

4 CONCLUSIONS

The analysis of hurdle clearing in the course of a 400 m hurdle race requires the consideration of multiple methodological issues (research needs) and aspects strictly related to the competition rules (Iskra and Coh 2011). The primary issue is being able to organize the research work in a way that allows the evaluation of the running technique with respect to both legs (*as lead legs*), "stronger" and "weaker". To reconcile both positions (scientific and training), certain basic specific exercises were selected for the analysis. The analysis allowed the following conclusions to be drawn from the analysis:

1. During a hurdle race, the knee joint bending angle was significant in differentiating between the technique of hurdle clearing using the "stronger" and "weaker" trail leg. Such differences were not observed in the case of the lead leg.
2. The resultant knee joint speeds cannot be differentiated between exercises (marching and running) performed with either leg.
3. In the case of 400 m hurdlers, the assessment of the technique of performing specific exercises refers to spatial (knee joint bending angle) and not temporal (in this case knee speed) parameters.
4. The leg movement trajectory for marching and running was completely different. In view of the above, the use of both forms of technical training for hurdling are of different significance in the organization of the training.

The presented paper has potential limitations. Study limitations are related to the number of athletes. The conclusions being drawn may be potentially not precise. Other limitations are related to the IMU mocap suits. Sensors placed on the athlete's body can move gently, which affects the accuracy of the measurement.

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APPENDIX – GLOSSARY

Lead Leg – the leg that approaches the hurdle first.
Trail Leg – the leg that is bent at the knee joint and positioned sideways behind the lead leg
Dominant Leg – the preferred (most frequently used) lead leg during a 400 m hurdle race
Opposite Leg – the leg that is used as lead leg in 400 m hurdle race only in the case of a change in the "stride pattern".