Kinematic Analysis of the Upper Limbs in Stepping over the Hurdle
The Use of IMU-based Motion Capture

Janusz Iskra[1], Krzysztof Przednowek[2], Tomasz Krzeszowski[3], Krzysztof Wiktorowicz[3], and Michal Pietrzak[4]

[1]*Faculty of Physical Education and Physiotherapy, Opole University of Technology, Opole, Poland*

[2]*Faculty of Physical Education, University of Rzeszow, Rzeszow, Poland*

[3]*Faculty of Electrical and Computer Engineering, Rzeszow University of Technology, Rzeszow, Poland*

[4]*Faculty of Physical Education, The Jerzy Kukuczka Academy of Physical Education in Katowice, Katowice, Poland*

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Abstract: This paper presents an analysis of the kinematic parameters of the upper limbs in stepping over the hurdle. Stepping over the hurdle is a specific exercise practised throughout the year. In this exercise, three key points were analysed in take-off, flight and landing phases. The aim of the study was to use the IMU-based (inertial measurement unit) motion capture system to evaluate the movement of the hurdlers' upper limbs while stepping over the hurdle using both the better leg, and the worse leg. The sequences were obtained using 18 sensors working at a frequency of 120 Hz. The analysis was made using two high-achieving athletes. This paper presents the linear velocities and the trajectory of selected segments of the upper limbs. In most cases the velocities of the segments were higher for the better leg. The analysis shows that during the specific exercise of stepping over the hurdle attention should be paid to the movement of the trail arm in the landing phase.

1 INTRODUCTION

Research in respect of hurdling is not only associated with the typical hurdle distances (100/110 and 400 m), but also with steeplechasing (Hunter et al., 2008), enthusiasts of physical effort clearing high obstacles (Mauroy et al., 2014) and random people clearing low obstacles (Austin et al., 1999). The hurdles race is a difficult athletics competition, where the technique for clearing an obstacle between 0.84-1.067 m high (depending on the distance of the race) is essential. These competitions are usually associated with lower limb movement, referred to in the literature as the 'lead leg' (the leg attacking the hurdle) and the 'trail leg' (the leg opposite the attacking leg). Active work by the torso is equally important when clearing the hurdle. This is proved by numerous scientific publications, which only analyse the kinematic and dynamic parameters of these elementary forms of clearing the hurdle (Salo et al., 1997; Čoh et al., 2008; Krzeszowski et al., 2015). Evaluation of hurdles techniques focuses primarily on assessing the individual phases of hurdle clearance. These phases are a complex form of dynamic movement.

Analysis of the kinematic parameters and the course of the hurdle race has a rich tradition (especially in respect of the 110 m race (Valamatos et al., 2005; Iskra and Coh, 2011)). In the most of researches (especially those having practical applications), authors not focus on upper limb movements (Salo et al., 1997; Li et al., 2011). Some rare studies are based solely on the observation of photos and kinograms of the best athletes in the world (McKinnon and Comerford, 2012). This problem is important in the course of the whole race, with particular emphasis on hurdle clearance (McFarlane, 2000; Krzeszowski et al., 2015). Therefore, this study attempted to analyse the movement of the upper limbs in stepping over the hurdle. Stepping over is a basic exercise in teaching the technique of clearing the hurdle. This exercise is performed throughout the year-long training cycle. It is also necessary during warm-up and while preparing for the season.

The aim of this study is to use the IMU-based motion capture to evaluate the movement of the hurdlers' upper limbs while stepping over the hurdle. The assessment of the kinematic parameters was based on the exercises being performed using both the better (dominant) leg, and the worse leg. Additionally, the

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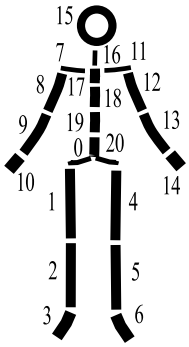
Table 1: Athletes' data.

	Athlete 1	Athlete 2
Age [years]	26	28
Body mass [kg]	80	74
Body height [m]	1.85	1.84
Personal best (400 hurdles) [s]	50.84	51.08



0 - Hips
1 - RightUpLeg
2 - RightLeg
3 - RightFoot
4 - LeftUpLeg
5 - LeftLeg
6 - LeftFoot
7 - RightShoulder
8 - RightArm
9 - RightForeArm
10 - RightHand
11 - LeftShoulder
12 - LeftArm
13 - LeftForeArm
14 - LeftHand
15 - Head
16 - Neck
17 - Spine3
18 - Spine2
19 - Spine1
20 - Spine

Figure 1: The structure of the skeleton estimated by the IMU-based system mocap along with the names of the segments.

method of clearing the hurdle by two top-class athletes was compared.

2 MATERIAL AND METHODS

Two hurdlers took part in the study. They both represented a high level of training and they participated in World and European Championships, and the Olympic Games. The basic data describing the athletes are presented in Table 1. The kinematic analysis included special exercises performed during the stepping. These exercises are the basis of hurdles training at every distance and are performed throughout the entire 12 month training cycle. Each contestant made two attempts to step over the hurdle. In the first attempt, he cleared the hurdle with the better leg, which is the leg that he uses more often to clear the hurdle. During the exercise, the athlete cleared the 1.067 metre-high hurdle. In the second attempt, the athlete attacked the hurdle with the worse leg. In clearing the hurdle, three time points were distinguished (Figure 3). The first point (P_1) is defined by the moment when the athlete positions himself to clear the hurdle. The second point is determined by the position of the athlete when both their legs are off the ground and the feet are at the same height. The third point is determined by the moment when the athletes put their lead leg behind the hurdle. During the clearance the athlete was not allowed to touch the hurdle with either leg. If the hurdle was touched the test was repeated.

The kinematic parameters of the stepping over the hurdle were collected using inertial sensors. The Perception Neuron system and Axis Neuron Pro (Noitom Technology, 2017) software were used in the study. The system consisted of 18 IMU sensors operating at 120 Hz. Each sensor consists of an accelerometer, a gyroscope and a magnetometer. The structure of the estimated skeleton is shown in Figure 1. The data were recorded wirelessly using WiFi. The main features of Axis Neuron Pro are: motion data recording/replay, motion data filtering/smoothing, system and sensors calibration, exporting data to .bvh and .fbx formats. Before each measurement, the system was calibrated. The data generated by the motion capture system (.calc file with global coordinates xyz of segments) were processed using the Matlab software (Figure 2). A script was developed that transformed the data into the common coordinate system and calculate the resultant linear velocities.

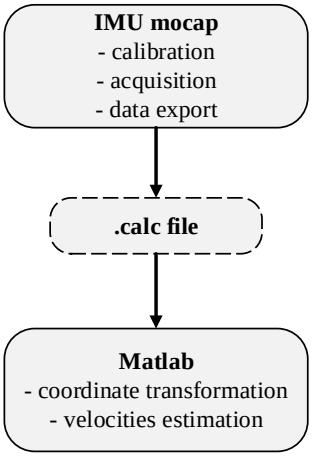
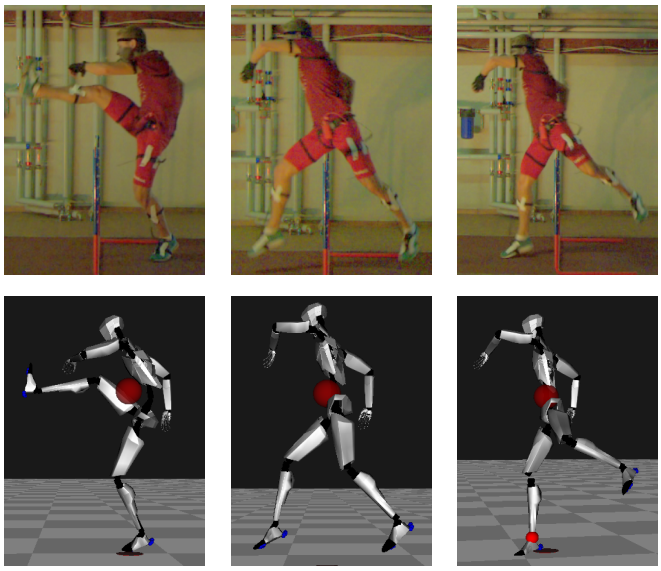


Figure 2: Data processing diagram.

3 RESULTS AND DISCUSSION

The basic element of the analysis was the calculation of the resultant linear velocity in the key points of the exercise (Table 2). Analysis of the data presented in Table 2 indicates significant differences in the velocity of the upper limb movement in the case of the attack with the dominant leg and its opposing upper limb. This concerns most of the analysed parts (arm, forearm and hand) in all points of motion (P_1–P_3). Athlete 1 demonstrated slight decreases in velocity compared with the worse leg attacking, only in case of P_2 for the lead arm and lead forearm. For athlete 2, this decline was recorded for the segments of trail arm, forearm and hand in P_2 and lead arm and forearm in P_3.

The most distinguishing feature of the upper limb



(a) (b) (c)

Figure 3: Key points of stepping over the hurdle; (a) P_1 - take-off, (b) P_2 - flight, (c) P_3 - landing.

Table 2: Velocity (m/s) of upper limbs in key points of stepping over the hurdle.

Segment	Lead arm		Trial arm		Lead forearm		Trial forearm		Lead hand		Trial hand	
Lead leg	worse	better	worse	better	worse	better	worse	better	worse	better	worse	better
Athlete 1												
P_1	1.2	1.6	0.9	1.3	1.3	1.6	0.9	1.3	1.2	1.5	1.2	1.6
P_2	1.8	1.6	2.3	2.3	1.9	1.7	2.3	2.4	2.1	2.2	2.2	2.6
P_3	1.7	2.0	2.3	3.1	2.2	2.5	2.6	3.7	2.9	3.5	2.6	4.2
Athlete 2												
P_1	0.9	1.7	0.7	1.9	1.2	1.6	0.9	2.1	1.1	1.2	1.2	2.5
P_2	2.0	2.3	2.5	2.4	2.3	3.1	2.9	1.6	2.8	4.1	2.7	1.4
P_3	3.9	3.7	3.8	4.6	4.9	4.8	4.0	5.4	5.8	6.3	4.0	6.0

movement during the exercise is the velocity of the trail hand motion in P_3. This is the element that trainers pay attention to (McFarlane, 2000). For athlete 1 the velocity difference for the trail hand was 1.6 m/s, while for athlete 2 it was 2 m/s. In this point (landing) the big differences were also seen between the competitors. Athlete 2 made considerably faster trail arm movements than athlete 1.

Another element of the analysis was to determine the trajectory of selected segments of the upper limbs. Figures 4 and 5 show arm and hand movement in space (height and distance). Analysis of the graphs indicates that the greater difficulty in stepping over the hurdle is more related to lead upper limb movement than to the trail upper limb. In particular, the biggest differences are noted for the lead hand (Figure 4(c) and 5(c)). Both athletes display a lack of symmetry of movement between the better and worse leg. However, in the analysed points, the lead and trail arm movement of athlete 1 shows some similarities (Figure 4(a, b) as opposed to athlete 2 (Figure 5(a, b)).

Analysing the trail hand (Figure 4(d) and 5(d)) it was noted that both athletes finish the move faster when clearing the hurdle with the better leg. This may suggest individual conditioning of the arms while clearing the hurdle with the better and worse attacking leg, which is consistent with the basic principles of the technique and the recommendations of trainers.

4 CONCLUSIONS

The paper presents the analysis of kinematic parameters of the upper limbs in stepping over the hurdle. The research used IMU-based motion capture system. The results for the considered points show that, in most cases, higher velocities were achieved with the better leg. Moreover, the analysis shows that attention should be paid to the trail arm movement in the landing. Difficulties in stepping over the hurdle (including those with the upper limbs) mainly concern movements of the trail arm performed during exer-

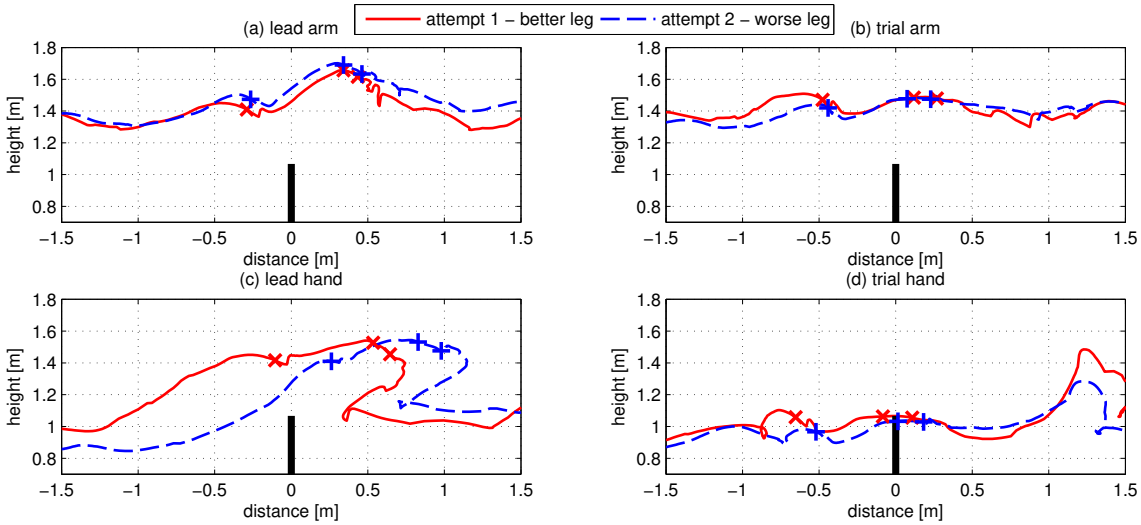


Figure 4: Movement trajectory of athlete 1. The symbols + and × mark the points P_1–P_3.

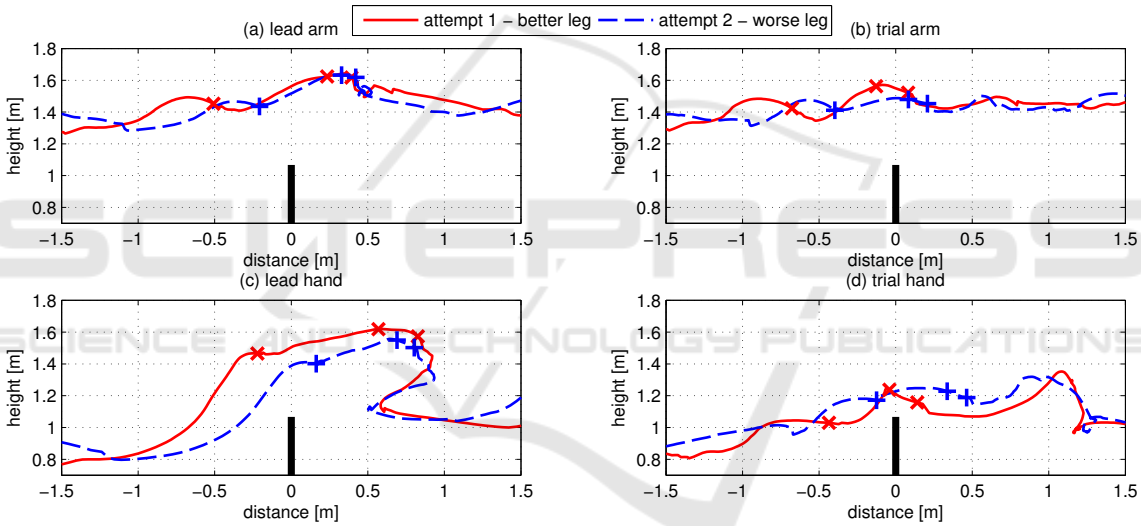


Figure 5: Movement trajectory of athlete 2. The symbols + and × mark the points P_1–P_3.

cises with the 'worse' leg.

Future work will focus on a comparison of the movement of the arms during other special exercises. Moreover, the number of athletes will be increased in order to draw more detailed conclusions on the movement investigated.

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