Journal of Physical Education & Health, 2020, vol. 9 (16), 37-47

https://doi.org/10.5281/zenodo.5196142

ARM ACTION IN HURDLE CLEARANCE IN GROUPS OF DIFFERENT AGES AND SPORT SKILLS

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Abstract
One of the key factors for improving hurdle performance is the development of advanced athletic technique, analysis of which is vital in monitoring the training process. The current discussion on hurdling technique, however, seems to overlook the aspect of the movements of the upper limbs in hurdle races. The aim of this study was the qualitative assessment of the upper limb movement in the hurdle step. This study involved three research groups: children, physical education students and hurdle race runners. A questionnaire designed by the authors was used to qualitatively evaluate the technique of clearing the third hurdle (obstacle), taking into account three moments in clearing the hurdle, i.e. the take-off, the over-the-hurdle position and landing. A video footage was captured using three synchronized cameras which recorded a 1920x1080 resolution video at 50 Hz. The results showed statistically significant differences for most of the variables considered. Among all three groups tested, significant differences were noted for flexion at the elbow joint and for movement at the shoulder joint.
Key words: *hurdle run, arm movement, athletics, model technique*

Introduction

Hurdles is a complex sports competition in which technique and motor preparation are equally important [1, 2]. The complexity of sprint hurdle race requires analysis of aspects such as fitness, coordination and mentality [3]. An advanced level of athletic skills and techniques in hurdling is a key element for high performance. Its analysis is one of crucial control factors for the training process. The technique of clearing any single hurdle changes during the run along with the successive hurdles. Adjusting the running technique in order to clear all 10 hurdles at maximal velocity is the top priority.

From a scientific point of view, observation conducted under field conditions as a control of the training component will be vital. A review of literature shows that hurdle race is missing standardized testing procedures and that research so far has focused solely on training and testing solutions to replace classical forms of competition for testing purposes [4].

The first attempts to evaluate hurdling technique were made using single or series of images of the best hurdlers of a given period. A preliminary kinematic analysis was performed and consulted with athletic experts. A pioneer in this field back in the 19th century was Montaque Shearman, who evaluated the hurdling technique of the first ever athletic match [5], which enabled an insight into differences in the participants' running styles. Scientific work based on the same research tools continued with Boyd Comstock and Frederick Webster describing the hurdling style [6, 7].

At the turn of the 19th and 20th centuries, the analysis of hurdles running technique evolved to include more accurate and comprehensive cinematographic methods, which made it possible to produce the so-called kinograms recording movement patterns. A pioneering analysis of hurdling technique using this method was performed by Toni and

Elfriede Nett in 1968. In their comprehensive study, they included kinograms taken at different events: 15 in 110-meter hurdles, 11 in 400-meter hurdles and 8 in 80-meter hurdles for women [8]. The usefulness of the method discussed is confirmed by numerous publications based on kinograms of Olympic, world and European champions. They were analyzed by, among others, Brejzer and Kajtmazowa [9], Buffault [10], Hommel and Arnold [11]. This was accomplished in the 100 meter hurdles by Hommel and Vernon [12] and in the 400 meter hurdles by Susanka [13], Brejzer [9] and Hommel and Schmid [14]. Other available analyses of hurdling techniques include those performed by Oberback [15] and Artyushenko and Bliegletov [16], with children as subjects in the studies. The most common way of analysing movement in hurdling competitions was to examine selected phases of a run or series of kinogram sequences recorded in performances by top athletes such as, for example, world record holders Renaldo Nehemiah [9], Roger Kingdom [17], and Colin Jakson [14].

The basic element in the technique of running over hurdles is clearance, also referred to as "the hurdle", "the fence step", or "the hurdle clearance" (cf. Čoh [18,19], McDonald [20]). This is the part of the run that begins the trail leg is placed in front of the hurdle and the lead leg is placed behind the hurdle. At this stage of the run, only the movements of the lower limb tend to be analyzed. A review of literature on hurdling technique in preparation for the current discussion, reveals that upper limb movement in hurdle runs is overlooked. This problem is crucial for overall performance in a race, yet becomes of premium importance at the moment of clearing the hurdle [3]. Little interest in this problem is evidenced by the fact that there is no unambiguous nomenclature capable of identifying elements of upper limb movement in descriptions of running technique, which could be unanimously accepted by researchers. The analysis of upper limb movements during hurdle clearance and selected special exercises requires clarification of nomenclature (Table 1).

Table 1. A review of upper limb movement nomenclature in hurdle race ranked according to validity of choice.

Upper limb	**„In front"**	**„In back"**
	Lead	**Opposite**
Arm	attacking lead arm	trail
	"on the side of the trail leg" "opposite to the lead leg"	"opposite to the trail leg" "on the side of the lead leg"
	"first arm"	"second arm"
	"right/ left arm"	"right/ left arm"

Objective

The aim of the study was to qualitatively assess the technique of upper limb movements recorded at the hurdle clearance phase in three research groups of different ages and advancement levels.

Materials and Method

Participants

Three groups participated in the study: Group I, n= 25; 5-6 year old preschool children, covered a distance of 30m with five cardboard hurdles twice with 5-minute intervals between the runs. The children were asked to clear cardboard hurdles as part of regular preschool activities. The run towards the first cardboard hurdle took about 6-9 steps (7 m), a number consistent with observations by Iskra [4]. The height of the hurdles was 60% of the average length of the lower limbs (0.30 m) and the distance between hurdles was 4 times the average body height (5 m). The trial, preceded by a warm-up game, was conducted on the premises of a private kindergarten "Stokrotka" in Racibórz.

For Group II, $n = 46$; PWSZ students, the standard distance between the starting line and the first hurdle was taken into account (the so called "distance of the first hurdle") run 13.72m, the height and spacing between hurdles consistent with Gasilewski [21]. The height for males was 75% of the mean lower limb length, h=0.69 m, with the hurdles set at a distance of 4 times the mean body height (7.20 m).

Group III (*n* = 35) consisted of athletes competing at the 2018/2019 U20 and national senior athletics championships. The study assumed a standard distance from the start line to the first hurdle (13.72 m). The height of the hurdles was 107 cm, spaced 9.14 m apart. Measurements were taken at the side stadium during the competition (Figure 1).

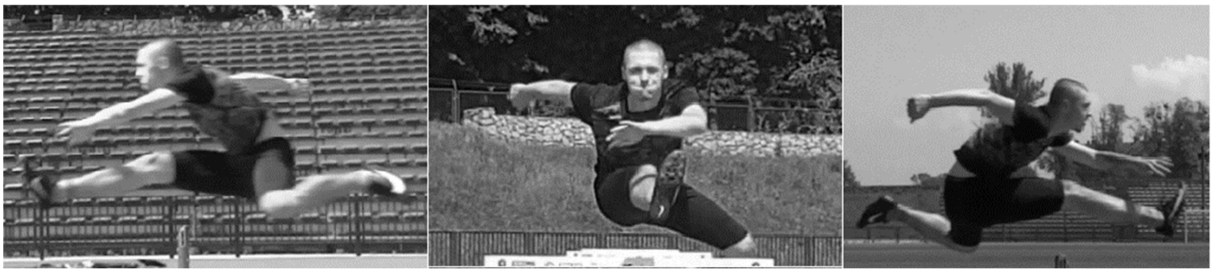

Figure 1. Photographic analysis of the flight phase (example)

Procedure

Due to the intervention nature of the study assessing upper limb technique in hurdle run, an expert method based on qualitative assessment of sport technique was used. An evaluation of hurdling technique based on photographic evidence was previously conducted by Bedini [22]. The trial consisted of two hurdle runs, with a distance of 60 m for the college students and hurdlers and 30 m for children participants. Trials were performed at the starting signal. The exercise was performed in a 3-step rhythm, with a break of 15 min between runs. Running over these distances and in this form is a basic exercise in hurdle training (hurdlers), in the teaching of physical education students and in games for young children [4, 23, 24].

The video material was recorded with the use of three synchronized Sony DSC-HX300 cameras that captured 1920x1080 resolution images at 50 Hz, positioned at 90° [25, 26] (Figure 2). The reference system was the horizontal edge of the fence. The filmed footage was later analysed by three experts, master and first class coaches, with a track record in training competitive hurdlers. In line with previous work [18, 20, 27, 28, 29], third hurdle clearance kinograms were used for analysis. All images were created with Kinovea software, which allows digital data to be downloaded from cameras and transferred to a computer (Figure 1). Three fundamental moments were identified: M2 (take-off), M3 (flight) and M4 (landing).

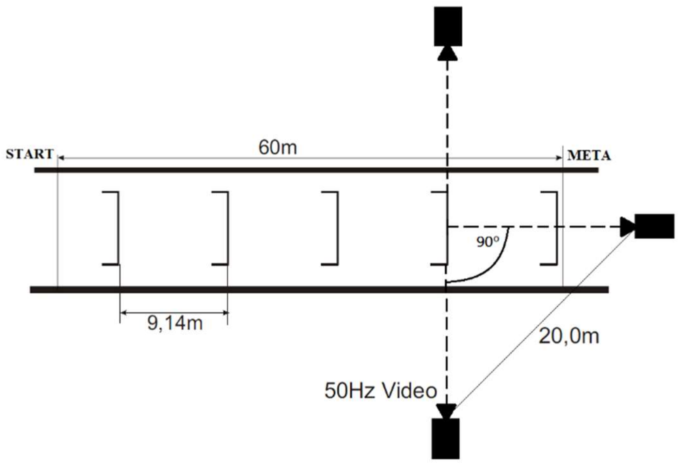

Figure 2. Measurement stand during the 60 m hurdles trial (based on Iskra et al. [30]).

A questionnaire was used to assess the hurdle technique, taking into account three moments of hurdle crossing (the take-off, the flight and landing), both upper limbs and two planes of movement (Table 2). In the qualitative assessment of the upper limb technique during hurdle crossing, 11 variants of the movement with the "attacking" upper limb and 11 in the movement with the opposite limb were used. Evaluation of the above 22 elements created a kind of a "map" allowing to pre-define movements of upper limbs during the hurdle crossing. The analysis of the hurdle technique was evaluated by three experts: coaches of hurdlers with numerous achievements in different age categories (from junior age to Olympic competition).

Table 2. Questionnaire designed for qualitative assessment of the technique recorded for both upper limbs at three phases of clearance.

Lead arm	**Trail arm**	
Variable – studied area		
I. Shoulder joint movement	**II. Flexion extension (to transverse axis)**	**III. Sagittal plane (to transverse axis)**
Flexion	No flexion (limb extended)	Superior to shoulder joint axis
Flexion and diagonal abduction	Flexion (obtuse angle)	Horizontally
Abduction		
Extension and diagonal abduction	Flexion (acute angle)	Inferior to shoulder join axis
Abduction		

* position of the arm in relation to the forearm, = flexion in the elbow joint
a - the assessor (expert) receives a detailed instruction to evaluate the technique of upper limb movement.

Statistical analysis

Variables testes are presented in the tables below. All statistical analyses were conducted using the STATISTICA 13.1 software, and the chi-square test was used to compare the groups.

Results

The analysis of the results obtained showed statistically significant differences for most of the variables considered. Among all three groups, significant differences were noted for most of the results obtained at the time of the take-off (Table 3). There were no statistically significant differences for the lead arm during movement at the shoulder joint and in the sagittal plane (respectively: p=0.841, p= 0.325). For both variables, the results were similar: the dominant movement was flexion and extension at the shoulder joint and extending the arm horizontally or above the axis of the shoulder joint. Significant differences were observed between the study groups for the trail arm (p< 0.01). The results obtained comprised all analyzed variables at the take-off time (Table 3).

Table 3. Intergroup differences for elbow joint flexion during hurdle clearance

Studied areas	Hurdle clearance	TAKE OFF					
	Arm		LEAD			TRAIL	
	Participants groups	H	S	Ch	H	S	Ch
I.	Flexion	34	44	25	0	0	0
	Flexion and diagonal abduction	1	2	0	0	2	3
	Abduction	0	0	0	9	7	18
	Extension and diagonal abduction	0	0	0	22	34	4
	Extension	0	0	0	4	3	0
	p		0.8419			0.0001	
II.	Participants groups	H	S	Ch	H	S	Ch
	No flexion (limb extended)	0	3	0	6	20	18
	Flexion (obtuse angle)	8	33	9	22	26	1
	Flexion (acute angle)	27	10	16	7	0	6
	p		0.0001			0.0001	
III.	Participants groups	H	S	Ch	H	S	Ch
	Superior to shoulder joint axis	10	13	13	0	1	4
	Horizontally	23	33	12	2	7	15
	Inferior to shoulder join axis	2	0	0	33	38	6
	p		0.325			0.0001	

Key: H- hurdlers, S- students, Ch- children, M2- take-off, M3- flight, M4- landing, p - chi-square test.

Another analyzed phase was the flight. Among all three groups tested, significant differences were noted for two variables: elbow flexion and sagittal motion (Table 4; $p < 0.05$). The differences concerned both the lead and the trail arm. There were no statistically significant differences for both upper limbs in shoulder joint movement ($p = 0.318$, $p = 0.930$, respectively). In the case of the lead arm, the movement in the shoulder joint was performed by flexion and diagonal abduction, and in the case of the trail arm, there was extension and the same diagonal abduction (Table 4).

Table 4. Intergroup differences for *the flight phase in the hurdle tests*

Studied areas	hurdle clearance	The flight					
	Arm	LEAD			TRAIL		
	Participants	**H**	**S**	**Ch**	**H**	**S**	**Ch**
I.	Flexion	15	19	12	0	0	0
	Flexion and diagonal abduction	20	27	9	0	0	1
	Abduction	0	0	3	10	13	9
	Extension and diagonal abduction	0	0	1	16	26	12
	Extension	0	0	0	9	7	3
	p	0.3188			0.9301		
II.	**Participants**	**H**	**S**	**Ch**	**H**	**S**	**Ch**
	No flexion (limb extended)	6	24	13	0	27	22
	Flexion (obtuse angle)	25	22	7	24	19	3
	Flexion (acute angle)	4	0	4	11	0	0
	p	**0.0051**			**0.0001**		
III.	**Participants**	**H**	**S**	**Ch**	**H**	**S**	**Ch**
	Superior to shoulder joint axis	1	0	10	1	4	1
	Horizontally	13	29	15	8	15	23
	Inferior to shoulder join axis	21	17	0	26	27	1
	p	**0.0001**			**0.0001**		

Key: H- hurdlers, S- students, Ch- children, M2- take-off phase, M3-flight, M4- landing, p - chi-square test.

The last stage analyzed was the landing. For all three variables, statistically significant differences were found among the studied groups (Table 5; p <0.01). These differences concerned both the lead and trail arm (p <0.001). The last phase analyzed was the landing upon completion of clearance. For all three variables, statistically significant differences were found among the study groups (Table 5; p<0. 01). These differences concerned both the lead and the trail arm (p<0. 001).

Table 5. Intergroup differences at the landing moment of hurdle clearance

Studied areas	Hurdle clearance	LANDING					
	Arm	LEAD			TRAIL		
	Participants	H	S	Ch	H	S	Ch
I.	Flexion	0	3	1	12	13	4
	Flexion and diagonal abduction	0	3	0	0	24	2
	Abduction	6	2	4	21	9	4
	Extension and diagonal abduction	25	16	7	2	0	15
	Extension	4	27	13	0	0	0
	p		**0.0051**			**0.0001**	
II.	**Participants**	**H**	**S**	**Ch**	**H**	**S**	**Ch**
	No flexion (limb extended)	3	27	16	0	13	22
	Flexion (obtuse angle)	29	19	4	28	33	3
	Flexion (acute angle)	3	0	1	7	0	0
	p		**0.0001**			**0.0001**	
III.	**Participants**	**H**	**S**	**Ch**	**H**	**S**	**Ch**
	Superior to shoulder joint axis	2	0	10	0	7	0
	Horizontally	13	29	15	2	19	10
	Inferior to shoulder join axis	21	17	0	33	20	15
	p		**0.0001**			**0.0002**	

Key: H- hurdlers, S- students, Ch- children, M2- take-off, M3- flight, M4- landing, p - chi-square test.

Discussion

Lead arm

The results of the intergroup analysis for the lead arm at the time of take-off were statistically significant for the elbow joint flexion variable. The similarity between the groups was evident with respect to shoulder joint movement, in which the subjects flexed and retracted the arm (forward movement). This is consistent with many other studies. According to Bedini [22], the lead arm action must be performed decisively forward and the forearm angle should be close to 90°. Similarly, believes Coly [31], assuming that in response to the movement of the lower limb attacking the hurdle, there is an extension of the opposite arm (the lead arm) forward, beyond the knee of the lower limb attacking the hurdle and upward (for the forearm of the lead arm). The lack of significant differences in movement in the sagittal plane indicates that the positioning of the lead arm during hurdles does not depend on the training experience and technical skills.

The results of the between-group analysis for the flight phase showed statistically significant differences for two variables: the movement of the limb in the shoulder joint and the flexion of the elbow joint. The majority of the hurdler group directed the upper limb arm inferior to the shoulder joint axis (downwards), which in synchronization with the lower limb aids a faster descent from the hurdle. This is in line with McKinnon [32] who states that "downward arm drive from a biomechanics perspective is beneficial when landing behind a hurdle." In addition, adopting this position is important in keeping the hip perpendicular to the hurdle and the task of eliminating twisting of the upper body. This is also confirmed by Obrocka [7], according to whom "(t)he upper limb opposite the attacking leg, extended forward, secures the balanced position of the trunk and shoulders." Unlike the hurdler, the students pointed their arm horizontally at the same time, which is also counted as a correct movement when clearing a hurdle. This is confirmed by Jolly and Winckler [33, 34], who note that: "the front lower limb and the opposite arm must move in parallel." Only among preschool children the limb position as inferior to shoulder join axis was not observed. In the flight position, the hurdlers maintained flexion of the upper limb to an open angle, which consequently allowed for greater control of their bodies. At the same time, among the remaining groups the lack of flexion in the elbow joint and maintaining this position up to the moment of landing were characteristic. The lack of flexion at the elbow joint is considered an error in the literature on hurdling methodology [24]. For the lead arm, movement at the shoulder joint was either through flexion and oblique inversion or flexion alone (forward movement). This proves/indicates similarity of movements performed in groups of different levels of technical preparation and ages. The position of the arm in this position is closely related to the position of the upper limb at the moment of the take-off. This is confirmed by Czwórnóg et al [35] and Studółka [36] that the movement of extending the lead arm forward is a continued position of the arm assumed at the take-off. This way of positioning the lead arm is in line with Coh's [18] research, in which the author demonstrates that the slightest vertical deviations of the centre of gravity of the body, head, shoulders and hips affect the efficiency of hurdling.

The timing of landing behind the hurdle appears to be crucial in assessing the upper limb technique due to intergroup variation. The straightening and inversion of the arm of the attacking limb was seen only in the groups of students and children. In many studies, this positioning is very unfavorable for continued running and is considered an error. Many authors agree with this, including Bedini [22] who believes that: 'running backwards' of the leading arm at landing causes rotation of the trunk and the shoulder girdle and thus may lead to the loss of relative balance. Also, for the elbow joint flexion there are noticeable differences between the athletes and the groups without hurdle training, however, the student group exhibit performance which bears more resemblance to that recorded in hurdlers. An obtuse angle for flexion at the elbow joint observed in the group of hurdlers was noted in less than half the group of the students and in a small number of the children tested. This may prove the positive impact of teaching techniques focused on improving the structure of the upper limb movement in hurdle races as well as developing the ability to adapt one's own muscle tensions, thanks to which the athletes maintain a stable posture while clearing a hurdle [37]. In a study conducted by Gasilewski and Iskra [17], physical education students took part in a 10-week hurdle clearance training program. Results obtained reveal that changes in hurdle run parameters (e.g. the height of the hurdle, hurdle spacing) affect performance, and consequently require further technical training of athletes for hurdle competitions. The improvement of the results in adult male hurdlers showed an increase in the level of motor abilities and technical skills in hurdling. Therefore, it can be concluded that the initial stage of instruction on developing motor skills provides the best training for hurdle race, and the importance of technical training increases at subsequent stages of hurdle training. Therefore, the results obtained in our study suggest that the variety of the lead arm movement techniques increases with each successive hurdle clearances in all tested groups, regardless of their levels.

Trial arm

The second part of the study focused on intergroup analysis for the rooted upper limb. The differences in movement patterns observed in the present study showed statistically significant differences during all moments in hurdle crossing. The only exception was the type of movement recorded for the shoulder joint in the flight position. According to hurdling practitioner Radiuk [38], the trail arm makes a slight movement with the elbow into a posterior-bottom position, lateral, yet not too far from the torso. The movement being closest to the characteristics thus assumed was evident for hurdlers and students. Additionally, differences in elbow joint flexion were demonstrated at the time of take-off. The student group showed little difference in the results between the dilation angle and the lack of flexion at the elbow joint. A lack of flexion at the elbow joint was noticeable in the performance of the majority of the child group.

The results of the intergroup analysis at the flight phase allowed us to observe differences in the technique for two variables. The recorded movement at the shoulder joint appeared to be similar for all groups. The subjects tended to perform straightening and inversion movements. It seems interesting to note that the groups tested showed a similar distribution of results obtained at the flight phase, which involved variable flexion and extension of the elbow joint as well as movement of the arm along the sagittal plane. The students re-directed the shoulder of the rooted upper limb inferior to shoulder join axis, the group of preschool children continued to position the arm horizontally and both groups again showed a tendency to lack flexion at the elbow joint. Again, it was shown that landing was the phase with highest variability of upper limb movement among the subjects. Differences were found in all variables adopted for the trail arm. Taking as a model the movement pattern observed in hurdlers, the student group showed more similarity than the preschool children. Changes in the structure of movement, which are noticed together with the tested group, highlight the importance of efficiency in the performed task (clearing the hurdle), and thus of the technical skill training.

Fang [39] also conducted a study on the efficiency of performance in hurdling. He found that the body height, the speed ability and the stride length had the greatest influence on the efficiency of running. Similar conclusions were reached by Iskra and Walaszczyk [4] who analysed the methodology for teaching children to hurdle with reference to parameters such as the hurdle height and hurdle spacing and their impact on the efficiency of hurdle run. As can be seen, most of the available studies are concerned with the temporal-spatial parameters of the lower limbs or the clearance structure. There is little research devoted solely to upper limbs, which leaves room for studies on this aspect of athletes' performance. Given that hurdles could be included in PE curricula in schools with an appropriate training base, this issue deserves more attention.

These data obtained in this study were not significantly different from the findings of Iskra et al. [30] concerning movement at the elbow joint of the trail arm. Factor analysis studies showed the contribution of the movement of the trail arm to both factors of the hurdle step technique (Factor I and II; 40.3% and 25.4% of the joint variance). They pointed out their particular excellent in the training process, assuming that the movements in this joint have high loads in both factors. This is why the correct operation of the upper limb can be an important part of the hurdling technique coupled with synchronized movement of the lower limbs.

Conclusions

The results of the present study verified the significance of the structure of upper limb movement in hurdling at all levels of ability. With few exceptions, upper limb movement significantly differentiates the study groups, especially at the landing phase. The difference lies in the movement of both the trail and the lead arm. Our results clearly showed that the elbow joint flexion during all three phases significantly differs between the tested groups. Good performance can be explained by appropriate training schedules, more experience in competing and training as well as the acquired skills. Therefore, special attention should be paid to the upper limbs in the early stages of courses on hurdling in the form of games and activities.

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Received: November 2020
Accepted: December 2020
Published: December 2020

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