Biomechanics Analysis of Bicross Start

M. Kalichová, S. Hřebíčková, R. Labounková, P. Hedbávný, G. Bago

Abstract**—**The article deals with a biomechanics analysis of the classic bicross start with a backward movement of the bike. This is a case study analyzing this type of start in two bicross riders representing the Czech Republic. Based on the 3D kinematic analysis and with a special emphasis on the ankle movement we have divided the start into five phases – phase n. 1 – reaction time, phase n. 2 – preparation movements time, phase n. 3 – first pedal stroke time, phase n. 4 – dead point pedal passage time, phase n. 5 – second pedal stroke time. Further we have demonstrated the significance of kinematic characteristics in various stages of the bicross start including their values and the extent of change. These primarily include the vector of the instantaneous velocity of the head, wrists, elbows, shoulders, hip and knee joints. The significant angle characteristics have been noted in elbow, shoulder, hip and knee joints. The results of this work indicate the types of movement prevailing in the respective phases and as such are expected to serve as a basis for further analyses of this movement structure performed, however, on a large research sample.

Keywords**—**Bicross, start, kinematic analysis.

I. Introduction

BICROSS is an individual sport with eight riders attempting to cover as fast as possible about a 350 metre long track with a number of various jumps. The track starts with a start hill approximately three to five metres high of the minimum tilt of 15°. Usually in the shape of a horseshoe or snake it tends to have three to four turns. The track's surface is solid, rolled flat with gravel or clay being used as the main material while turns may be treated with an asphalt surface. Following its acceptance as an Olympic Games sport an extreme branch of bicross has developed, the so called supercross. The main difference between the two include the height of the start hill in excess of 10 metres which may produce a speed of up to 50 km.h^{-1} upon the hill descent and long jumps in excess of 10 metres on the track in supecross.

Although the origins of bicross date back as early as the 1960's, the methodology of its sports practice based on biomechanics, kineziology and physiology studies has not been sufficiently elaborated. Besides that there is a lack of specialists and coaches engaged in this area. According to the information available, Boros [1] seems to be the first one to have investigated a bicross start with Ruffell and Evans [2] to follow later. The start technique has changed, however, since then. Based on the experience from competition races as well theoretical analyses of the bicross race performed earlier [3], [4] we have decided to deal with the bicross start whose quality is decisive in determing the success of the race [5], [6].

Due to the high demands on both coordination and acceleration a start is one of the most important determinants of the success of the whole race as well as one of the most complex and complicated of its phases. A start is thus conditioned by a combination of reaction, speed-force and coordination abilities [7], [8]. Besides these abilities Gianikellis et al. [9] identify a racer's technical competence as an important variable impacting on the quality of the performance of a start. Mateo, Blasco-Lafarga a Zabala [10] presented a study which determined the relationship between cyclic speed production, acyclic periods and characteristics of various phases of a BMX race. The study found that power and velocity performance were dependent on the track phases, techniques, and difficulty of the race.

A. Start Performance Technique

A start from a start facility using two pedals currently represents the fastest performance of a start under which three types of start are recognized [8]: a pushed start, a classic start with a movement of the bike backwards and a "slingshot" start. The start movement needs to be initiated much earlier than the ramp drops as the rider needs to be already moving forward when the ramp falls to the floor. Movement initiation differs with each individual but with the most riders it starts right upon noticing the first light or sound signal.

The classic type of bicross start with the backward bike movement which represents the most common type of start will be dealt with from the biomechanic perspective in our work. This type of start is based on coordination and synchronization of the body movement with the movement of the grid based on a light or sound signal. Both Lefebvre [7] and Dorémus [8] divide this start into two phases – a backward movement of the bike phase and acceleration phase, i.e. a start facility exit phase. The following is the brief characteristics of this start technique. The rider props the bike against the start facility. He is standing on his bike and fixes his pedals so that his stronger (starting) foot is put forward and the back foot is approximately at the height of the back structure of the bike. Both legs are slightly bent. The height of the pedal depends on the tilt of the start hill. The body is tilted

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slightly backwards so that the arms are slightly bent in the same way as the front leg. The back should be kept straight with the position of the head depending on the type of stimulus. If he starts to light signals, with his head up the rider is watching the lights placed below the start hill. In a start to a sound signal the rider's gaze is fixed on the ground right behind the start ramp, his head thus in alignment with the spine. Before he initiates a movement by drawing the hips towards the handlebars the rider keeps balance on the bike. The shoulders are moving forward, they are situated approximately above the handlebars, the neck is in alignment with the spine, the head is bent down and the look is fixed on the front wheel (see Fig. 1). At the same time the rider slightly lifts the bike up and pushes the pedal down with the front foot while the back foot pulls the pedal up.

Based on a previous pilot study [4] we are convinced that in order to perform a deeper analysis of a start movement it is necessary to divide this complex movement structure into several phases based on the respective key movements performed by a rider and discuss their characteristics in detail.

II. Methods

Through a 3D kinematic analysis this case study aims to show the significance of various kinematic characteristics of individual phases of a bicross start including their values and the extent of change. The results of this work are intended to serve as a platform for further analyses of this movement structure using a larger research sample.

In selecting tested persons suitable for measurements an emphasis was laid on their high performance, technical performance of a start and stable performance record at a start. As a result two riders representing the Czech Republic were chosen.

A. Tested Person n. 1 (TP1)

Woman, 22 years old, has competed since the age of six, height 168cm, weight 65kg.

TP1 is a member of the Czech national bicross and fourcross teams. She got medals from the World as well as European championships. She practices a bicross start throughout the year, off season once a week, in the race season two to three times per week.

B. Tested Person n. 2 (TP2)

Man, 21 years, has competed since the age of five, height 182cm, weight 88kg.

TP2 has been a permanent member of the Czech national bicross team since his junior years during which he achieved impressive results, namely two Czech Republic Champion titles, and consistently ranked in the top 8 in European Championships competitions. After joining the elite category he still achieves high rankings in races held in the Czech Republic. In the same way as TP1 practice of a start technique forms a part of his practice throughout the year. Off season it is once or twice a week while in the race season two to three times a week.

After a necessary warm-up and a short starts drill both persons underwent five measured starts. On the basis of consultation with them and their coach the best performance was chosen for analysis. During practice measurements were carried out just before the start of the race season. Both TPs were in a good shape both physically and healthwise.

To obtain data a kinematographic method was used. The recording was carried out using two high frequency synchronized digital cameras SIMI Motion with the frequency of 100 shots per second. The recording was then processed using the SIMI Motion software produced by the German company SIMI Reality Motion Systeme GmbH. The tested persons were provided with reflex marks which facilitated easier videorecording assessment. All major joints were marked – wrists, elbows, shoulders, hips, knees and ankles. Following recording the data was further processed on a computer using the SIMI Motion programme. Only the best, i.e. the fastest time measured from the moment the red starting light came on till the end of the second pedal stroke, performance was chosen. Only the parameters with a major impact on the correct performance of the technique were chosen for analysis.

III. Results

A. Movement Phases of a Bicross Start

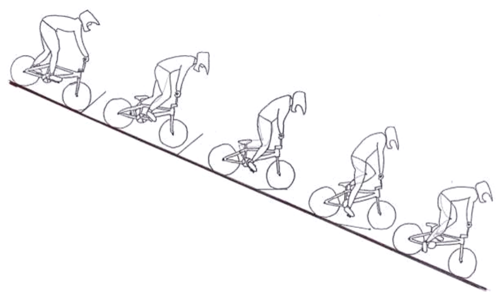

Fig. 1 Kinogramme of a bicross start performance – phases 1-5

Based on the measurements and an analysis of results five different stages can be recognized (see Fig. 1). The movement of the ankle, especially its instantaneous velocity, seems to be particularly important in all the five stages. Fig. 2 shows clearly the boundaries between the stages formed in response to the change of this variable.

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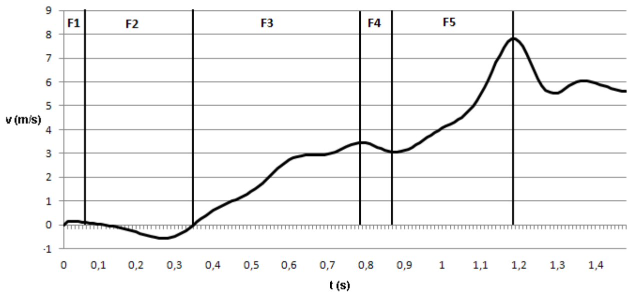

Fig. 2 The dependence of velocity on the front lower limb ankle movement time in TP1

Phase 1 – Reaction time starts in the time of 0 seconds and finishes at the moment of movement initiation. The phase is characterized by the velocity of reaction to a simple signal. During this phase the TPs assume their start position and are at rest.

Phase 2 – Preparation movements, it lasts from the moment of initiation of movement of individual segments and finishes at the moment of the first pedal stroke. That is to say the movement of the first foot, i.e. the first pedal stroke, is delayed in comparison with movements of the parts of the body. The first pedal stroke forward is preceded by a dominant movement of the upper part of the body.

Phase 3 – **First pedal stroke**, it lasts from the moment of the first pedal stroke till its finish. The feet line is situated horizontally with the ground. The first pedal stroke is finished when the cranks are perpendicular to the ground. The ankles then only copy a trajectory of one quarter of a circle. Phase 3 is dominated by the movement of the lower limbs where the first foot pushes the pedal down while the back foot pulls it up.

Phase 4 – Dead point pedal passage is given by a time delay between the first and the second pedal stroke. The phase commences when the pedals are positioned vertically with the body above them. With the backward movement of the pelvis and the erection of the body trunk a bike is simultaneously pushed forward. The phase is finished with the beginning of the second pedal stroke, i.e. with the beginning of the pedal movement forward.

Phase 5 – Second pedal stroke from its start till its finish. The end of pedal stroke occurs when cranks are perpendicular to the ground which means that unlike the first pedal stroke the ankles move by the angle of 180°. The phase is characterized by the dominant work of the lower limbs and as with the first pedal stroke one foot exerts a pushing force while the other exerts a pulling force which means the ankles are moving with acceleration.

Both the riders took almost the same time to perform these phases; TP1's was able to perform a start in 1.165 s while TP2's time was 1.126s. The following table shows the time length of individual phases in TP1 and TP2. The values for both riders are very similar, with the first phase, i.e. reaction time, being the shortest one (5.2 – 5.9%) and phase 4, i.e. dead point pedal passage, being the second shortest one. Phases 2 and 5, i.e. preparation movements and second pedal stroke respectively, showed approximately the same values accounting for 23.8 - 29% of the total time. The third phase, i.e. the first pedal stroke turned out to be the longest one in both the riders (32.5 – 36.5%).

TABLE I
LENGTH OF TIME OF INDIVIDUAL PHASES OF A BICROSS START

phase	time (s)	time (%)	time (s)	time (%)
	TP1	TP1	TP2	TP2
1	0.069	5.9	0.059	5.2
2	0.277	23.8	0.286	25.4
3	0.424	36.4	0.366	32.5
4	0.099	8.5	0.089	7.9
5	0.296	25.4	0.326	29.0
total	1.165	100	1.126	100

The major parameters observed in a more detailed analysis included the main joint angles, i.e. the elbow, shoulder, hip and knee, their change during movement, velocity and the order in which individual segments become involved. The following tables show selected data only.

1. Phase 1 – Reaction Time

In this phase the rider finds himself in a preparatory position which needs to be further specified because its purpose is to create conditions for the first movements following the start signal.

In tested person 1 the sharper elbow and shoulder angles in the right half of the body (see Table II) correspond to the lateral deflection and tilt of the body trunk over the right lower limb which is positioned forward. This is also evidenced by a smaller angle in the right hip joint. We may also observe a significant difference between the angles in the right and left knee which is caused by the pelvic tilt beyond the centre of the feet line. The tilt is very sharp with the centre of gravity shifted significantly backwards.

TABLE II
START POSITION – SELECTED JOINT ANGLES

joint	TP1		TP2	
	angle (°)		angle (°)	
	Left side	right side	left side	right side
elbow	162	150	157	155
shoulder	101	90	95	97
hip	90	88	78	89
knee	131	171	149	142

In TP2 almost the same values were observed for the elbow and shoulder angles (see Table II) which show TP2's symetrical positioning of the body and the arms. Even distribution of weight on the handlebars may therefore be expected while the difference displayed by the right and left hips is caused by the rider's position on the pedals with the left foot being shifted slightly forward. Similarly to TP1 a sharper angle in the right knee is indicative of the pelvic position beyond the feet line.

2. Phase 2 – Preparation Movements

In a data analysis time 0 s was defined as the moment of the red light coming on. This is actually the very first signal to be perceived by the rider prior to the beginning of the race movement. The speed of reaction to this signal stood at 0.069 s for TP1 which is an above-average value. The left knee becomes involved in the movement significantly earlier and thus initiates phase 2. Also the wrist becomes involved in the early stages of the movement with the other segments following slightly later on almost simultaneously. The movement of the left wrist, elbow and head is followed by the movement of the shoulders, hips, right knee and ankle. In TP2 the movement is initiated in the left elbow at the time of 0.059 s which again is an above-average value. This is followed by the movement of the other elbow, both wrists, knee and ankle of the right (back) foot. The movement of the back foot is transferred to the movement of the hips and shoulders. The right (front) foot and the head are the last body parts to become involved. The left shoulder and elbow become involved in the movement slightly earlier than the respective parts on the right side which leads us to assume that the rider is tilting slightly to the left, i.e. over the front foot which is producing a pushing force. The difference displayed by TPs consists in the involvement of shoulders and elbows in the movement which impacts on the weight transfer either on the right or left half of the body. In the case of TP1 the shoulders and elbow get involved simultaneously. This is because the description of the start position says TP1 has transferred her body weight over the front foot prior to the movement initation while TP2 transfers his body weight over the front foot upon the movement initiation, his shoulder and elbow therefore get involved earlier on this side than on the other side.

Fig. 3 Initial and final position during phase 2

Phase 2 lasting from the movement initiation till the beginning of the first pedal stroke (see Fig. 3) is characterized by the transfer of the body mass forward and over the front foot.

TABLE III
TP1 PHASE 2

observed variable	segment	right side phase beginning	right side phase end	left side phase beginning	left side phase end
velocity (m/s)	**head**	**0.078**	**1.589**		
	wrist	0.075	0.666	0.354	0.975
	elbow	0.760	0.575	0.226	1.278
	shoulder	**0.165**	**0.982**	**0.088**	**1.312**
	hip	**0.263**	**1.181**	**0.069**	**1.899**
	knee	0.277	1.220	0.195	0.735
	ankle	0.069	0.504	0.172	0.530

TABLE IV
TP2 PHASE 2

observed variable	segment	right side phase beginning	right side phase end	left side phase beginning	left side phase end
velocity (m/s)	**head**	**0.082**	**1.598**		
	wrist	0.077	0.838	0.180	0.473
	elbow	0.272	1.156	0.204	0.352
	shoulder	**0.082**	**1.093**	**0.090**	**1.370**
	hip	**0.037**	**1.179**	**0.083**	**1.570**
	knee	0.065	0.812	0.020	0.809
	ankle	0.094	0.436	0.094	0.436

Tables III and IV show the original and final values of the observed variables in phase 2 in both TPs. The velocity increase of individual body parts shows a similar trend in both TPs, in some segments it is even the same. It is also noteworthy that the velocity of segments at the end of the phase is higher in the left half of the body in both TPs despite each of them using a different foot to push the pedal (TP1 – right, TP2 – left). This may be influenced by different rotation of the body trunk.

3. Phase 3 – First Pedal Stroke

Phase 3 lasts while the first pedal stroke is being performed. This means it is very short because the front foot is almost horizontal to the ground in the beginning of the phase while at its end it is situated at the lowest point, i.e. when the cranks are perpendicular to the ground. The foot then copies a trajectory of a quarter of a circle only (see Fig. 4). The movement of lower limbs is the most dominant as well as most important movement of this phase where each foot performs a different function. The first foot pushes the pedal down while the back one pulls it up. The magnitude of acceleration of the whole movement is set by the magnitude of force exerted on the front pedal. Besides the muscle force exerted on both pedals there is also the gravity force acting on the first pedal. As for the magnitude of acceleration the resultant of the forces acting on this pedal is therefore much higher and more dominant.

Fig. 4 Initial and final position in phase 3

The following table shows the values recorded at the beginning and end of phase 3 with the velocity of knees and ankles and the knee joint angle being the most important values.

TABLE V
TP1 PHASE 3

observed variable	segment	right side		left side	
		phase beginning	phase end	phase beginning	phase end
velocity (m/s)	shoulder	0.982	4.888	1.312	4.341
	hip	1.181	2.919	1.899	3.322
	knee	**1.220**	**2.584**	**0.735**	**2.876**
	ankle	**0.504**	**3.600**	**0.530**	**4.443**
angle (°)	hip	11.997	154.528	114. 977	88.037
	knee	**145.520**	**168.241**	**127.145**	**88.969**

TP1 does not show a linear growth in the knee and ankle velocity. In the first phase of pedal stroke the movement acceleration tends to be slower with the values hovering at about 1.4m.s^{-2} (see Table V). This is when the foot pushes the pedal down and the pedal's resistance prior to the bike movement is high. In the second stage of the movement the velocity growth is much faster with the acceleration reaching the value of approximately 10m.s^{-2} (see Fig. 5). The ankles' acceleration magnitude does not change throughout the rest of the first pedal stroke with the highest velocity values being 3.6 m.s^{-1} a 4.4m.s^{-1} for the right and left ankles respectively at the end of the phase. These values display a downward trend in the next movement phase. The knees, however, show slight deceleration just before the end of the phase as can be seen from Fig. 5. This may be caused by the change in the knee joint angle which slows the knee movement down.

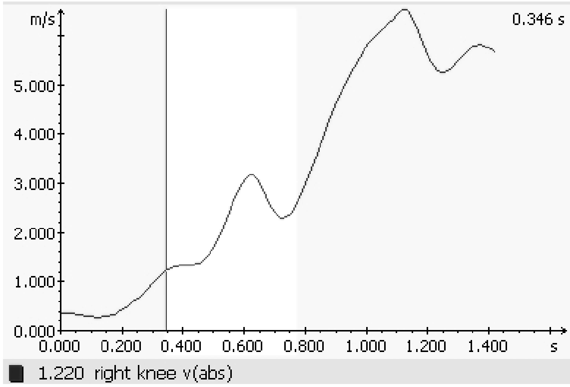

Fig. 5 Right knee velocity change in TP1 in phase 3

TABLE VI
TP2 PHASE 3

observed variable	segment	right side		left side	
		phase beginning	phase end	phase beginning	phase end
velocity (m/s)	shoulder	1.093	3.893	1.370	3.878
	hip	1.179	2.954	1.570	3.154
	knee	**0.812**	**5.290**	**0.809**	**2.559**
	ankle	**0.436**	**6.127**	**0.436**	**3.795**
angle (°)	hip	119.168	99.962	93.979	115.624
	knee	**135.854**	**84.409**	**130.063**	**148.250**

In TP2 the ankle and knee velocity growth is more fluent than in TP1. The graph showing dependence of velocity on time does not show the initial deceleration of the movement of various segments (see Fig. 6). Both acceleration and the final velocity are much higher on the right side, i.e. by the back foot – 6.1m.s^{-1} than on the left side – 3.8 m.s^{-1} (see Table VI). The acceleration value for the left ankle stands at approximately 9m.s^{-2}, on the right side it is in excess of 12 m. s^{-2}. Due to the employment of cranks the both feet form one system which in theory should move equally fast on both sides. The observed difference in acceleration and thus the final speed is likely to have been caused by the change in the ankle joint, or the knee joint.

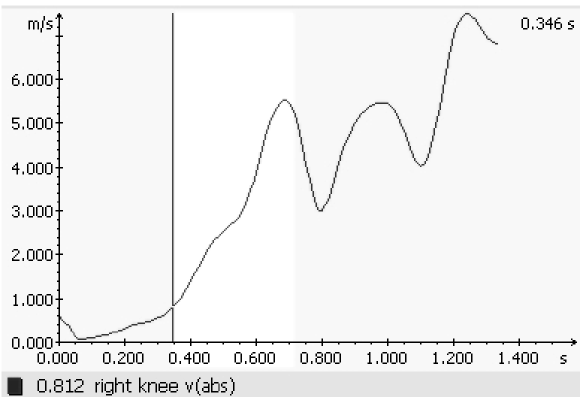

Fig. 6 Right knee velocity change in TP2 in phase 3

The final velocity of individual lower limb segments and the average acceleration values tend to be higher in TP2. Also there was no initial deceleration of the movement in TP2 observed which most probably resulted from a larger force exerted on the pedal which had resulted from better strength preparation of TP2 which is to a large extent affected by the rider's sex.

4. Phase 4 – Dead Point Pedal Passage

Phase 4 starts after the first pedal stroke when the cranks as well as the pedals are perpendicular to the ground and the body is positioned above them (see Fig. 7). The force exerted on pedals by lower limbs at this moment is acting towards the centre of the crank rotation axis and therefore it has no rotation effect on them. For this reason the body mass is transferred backwards beyond the bike's centre in order to change the direction in which the lower limbs act on pedals. The phase is finished upon the beginning of the second pedal stroke.

Fig. 7 Initial and final position in phase 4

As is obvious from the angle change (see Table VII) TP1 performs two simultaneous movements during this phase. These are the backward shift of the pelvis and the forward push of the bike. During the backward pelvic shift the right hip angle is reduced from 154.5° to 127.5°. There also occurs a dramatic change in the top leg knee angle. The left leg gets extended in the hip joint from 89° to 125° as a result of the pelvic shift. The resulting increased shoulder angle is caused by pushing of the bike forwards.

TABLE VII
TP1 PHASE 4

observed variable	segment	right side: phase beginning	right side: phase end	left side: phase beginning	left side: phase end
velocity (m/s)	hip	2.919	3.933	3.322	3.995
	knee	2.584	4.097	2.876	3.524
	ankle	3.600	3.076	4.443	4.743
angle (°)	elbow	151.286	150.122	145.026	163.251
	shoulder	**43.117**	**55.564**	**49.704**	**74.682**
	hip	**154.528**	**127.505**	**88.037**	**81.614**
	knee	**168.241**	**165.718**	**88.969**	**125.045**

In TP2 the increased left hip joint angle (from 115.6° to 120.3°) and the increased left knee joint angle (from 148.3° to 168.2°) (see Table VIII) at the end of this phase indicate that TP2 does not tend to shift the pelvis as far back as TP1, on the contrary he tends to straighten the trunk, i.e. he extends it. His shoulder joint angles tend to change similarly to TP1.

TABLE VIII
TP2 PHASE 4

observed variable	segment	right side: phase beginning	right side: phase end	left side: phase beginning	left side: phase end
velocity (m/s)	hip	2.954	4.092	3.154	3.914
	knee	5.290	3.010	2.559	3.495
	ankle	6.127	5.696	3.795	3.109
angle (°)	elbow	105.815	131.124	108.130	120.622
	shoulder	**50.600**	**76.881**	**40.729**	**56.290**
	hip	**99.962**	**74.924**	**115.624**	**120.304**
	knee	**84.409**	**103.026**	**148.250**	**168.227**

5. Phase 5 – Second Pedal Stroke

Phase 5 represents the final phase of the start movement during which the second pedal stroke is performed which unlike the first one is complete, meaning that the foot copies a trajectory of a semi-circle (see Fig. 8). The work of legs is dominant again and like with the first pedal stroke one foot is exerting a pushing force, the other one a pulling force.

Fig. 8 Initial and final position in phase 5

As is recorded in Table IX, TP1 shows an increased velocity of the lower limbs movement, which is more pronounced in the right lower limb, more specifically in the knee joint and ankle joint, from $4.1 m.s^{-1}$ to $6.2 m.s^{-1}$ and from $3.1 m.s^{-1}$ to $7.3 m.s^{-1}$ respectively. The acceleration stays relatively the same throughout the whole time reaching the values of up to $16 m.s^{-2}$ in the right foot but hovering at around $8 m.s^{-2}$ in the left foot. This difference may be attributed to a varying change in the knee joints angle where the angle change is 77° in the right lower limb and 33° in the left lower limb. This significant difference may be the cause of the higher acceleration values and the final velocity values for the right lower limb.

TABLE IX
TP1 PHASE 5

observed variable	segment	right side phase beginning	right side phase end	left side phase beginning	left side phase end
velocity (m/s)	hip	3.933	5.392	3.995	5.308
	knee	**4.097**	**6.161**	**3.524**	**4.537**
	ankle	**3.076**	**7.838**	**4.743**	**5.107**
angle (°)	elbow	150.122	156.953	163.251	133.115
	shoulder	55.564	52.759	74.682	35.510
	hip	127.505	100.861	81.614	137.078
	knee	**165.718**	**88.762**	**125.045**	**158.260**

According to the values presented in Table X TP2 achieved higher final values for individual lower limb segments than TP1 did which is also given by higher movement acceleration values which stand at 17m.s^{-2} and 9m.s^{-2} for the ankle joint of the left and right lower limb respectively. The difference in the final values between the right and left lower limb may therefore be again accounted for by the change in the left lower limb knee joint, i.e. by the flexion from 168.2° to 104.4°.

TABLE X
TP2 PHASE 5

observed variable	segment	right side phase beginning	right side phase end	left side phase beginning	left side phase end
velocity (m/s)	hip	4.092	4.813	3.914	5.394
	knee	**3.010**	**4.363**	**3.495**	**6.034**
	ankle	**5.696**	**5.342**	**3.109**	**8.600**
angle (°)	elbow	131.124	100.193	120.622	145.016
	shoulder	76.881	44.216	56.290	70.592
	hip	74.924	119.304	120.304	87.358
	knee	**103.026**	**161.578**	**168.227**	**104.442**

IV. DISCUSSION

The entire start movement of the bicross rider represents a rather complicated movement structure which may be divided into five phases. As was shown by the results of the measurements, a rider is required to focus on different movement characteristics in each stage while trying to achieve their optimization which would lead to the shortening of the start procedure which is the rider's main goal. Let us now have a closer look at the assessed data and its interpretation, i.e. the specifics of the five phases.

In the first phase the rider assumes a preparatory position characterized by the backward position of the body centre of gravity. This position is given mainly by the position of hip joints which in turn is affected by the knee joint angles. Both knee joints are slightly flexed, Lefebvre [7] recommends the angle of 15 - 45º. In TP1 the recorded angles were 8º and 49º for the right and left lower limb respectively which signals a laterally imbalanced posture and the values thus stand outside the recommended range. In TP2 the angles are almost identical for both knee joints (31º and 38º) and their size is therefore convenient. The rider does not remain in this position for long, only during the reaction to the visual or sound stimulus. Gianikellis [9] considers the speed of the reaction to the start signal to be one of the most important factors of the start techniques. According to our measurements, however, the total time of this procedure is between 0.6 - 0.7s, which only accounts for about 5-6% of the total start time. From this perspective we consider the formation of the right posture which will create the optimal conditions for the first movements of the following stage to be the most important goal of the first stage. In this respect the slight flexion of the knee and hip joints, where respective muscle groups are in isometric contraction and where their pretension allows fast movement initiation, is viewed as very important. Through isometric muscle activity the rider is also able to keep the body in balance prior to the start.

According to our results the second phase accounts for about 25% of the total start time in both measured racers almost equally, which makes it a very important phase whose shortening will show considerably on the length of the whole start. This start is characterized by preparation movements preceding the first pedal stroke forward. The most significant increase in velocity may be observed in the head, hips and shoulders which through their movement forward transfer the body centre of gravity over the first foot and thus overtake the movement of the legs forward. Timewise, a back lower limb is the first one to get involved. It gives an impulse to a movement which transfers forward through the hips to the shoulders down to the front leg which is the last body part to get involved. As the start movement is initiated much earlier than the start gate drops, the lower limb segments first tend to go against the positive direction of the movement. Through the movements of this phase the lower limb joints become highly flexed. Our results therefore confirm Dorémus's [8] statement that the purpose of these movements is to accumulate in the stretched muscles as much as elastic potential energy as possible to be consequently used in performing mechanic work. With regard to the following phase the fast transfer of the body mass forward turns out to be the most important step. This transfer is carried out through the engagement of the kinematic chain of body segments starting from the back lower limb through hips up to the shoulders. As Dorémus [8] emphasizes the movement of the shoulders over the handlebars will prolong the phase of pressure exertion on a pedal and restrain the pelvic lift which should move forward in line parallel with the inclined plane even during the bike lift. Also Gianikellis et al. identifies the forward tilt as one of the important factors affecting the performance of a start. As measurements have shown a fast performance of this forward transfer of shoulders is conditioned by the support of the back lower limb and the consequent right and timely engagement of the respective muscle groups.

The third phase which equals the first pedal stroke forward is the longest one. According to our measurements it accounts for about 33 - 36% of the total time. In this phase the movement of the hips towards the handlebars continues through which the rider augments the momentum of the first pedal stroke as Lefebvre [7] explains. Simultaneously one foot exerts a pressure onto the front pedal, while the other foot pulls the back pedal up. During this movement nearly all the joints switch from flexion to extension by which the accumulated elastic potential energy in eccentrically concentrated muscles is used. There also occurs an increase in the velocity of ankles and knees. This phase aims to perform the first pedal stroke with maximum acceleration which is conditioned by a large level of explosive force of lower limb extensor muscles. Based on our research we assume that the insufficient level of this strength ability shows in the non-linear velocity growth which results in both a lower velocity of lower limb segments at the end of this phase as well as a longer time it takes to perform this stage. We also believe that the velocity progression of the observed segments may also be affected by the timing and the extent of the above-mentioned hip movement forward.

Phase 4 is characterized by a marked decrease in the ankle movement velocity. This deceleration is caused by the position of cranks where pedals are situated in the dead point which the rider has to pass through. The forces so far exerted by the lower limbs, i.e. upwards and downwards, stop producing their rotation effect as both are directed at the centre of crank rotation. That is why it is in this phase that the centre of gravity is transferred backwards beyond the bike's centre in order to facilitate the change in the direction of the force exerted by the lower limbs on the pedals. In this phase of the start movement, simultaneous performance of the following movements may be observed: backward pelvic shift, extension of the body trunk and the forward push of the bike upon ventral flexion of the shoulders. The coordination of this phase is extremely demanding especially if we consider that riders are supposed to perform it in a very short time in order to be able to commence the second pedal stroke as soon as possible and thus leave the start facility ahead of their competitors. As the measurements have shown, this is only 0.09 – 0.1s which accounts for approximately 8% of the total time.

The primary goal of the fifth phase is the fastest possible performance of the second pedal stroke. This phase is the second longest phase of the whole observed movement structure; in our tested persons it accounted for 25 - 29% of the total time. Its optimal performance, i.e. maximum acceleration of the movement of the lower limb segments is, like in phase 3, conditioned by strength abilities of the racer. However, technical side of the movement task which stems from the previous phase is very important too. In phase 4 the rider is supposed to get into the optimal position to be able to exert the maximum force on the pedals.

The above-mentioned undertaken study of the movement structure of the bicross start movement indicates which most important variables affect its performance as seen from the biomechanic perspective. To reveal the key relations and connections it is imperative to focus on the characteristics of each individual phase separately and analyze them on a larger number of tested persons.

V. Conclusion

Due to a low number of tested persons it is impossible to draw generally valid conclusions. For this reason this case study may serve as a platform for further more extensive research which could compare the technique using a larger sample of participants. From this perspective we are convinced that the division of the bicross start into phases based on the kinematic analysis of the start preparatory position and on the changes of kinematic parameters during the first movement of the start represents the most important findings of this study. The results led to the creation of the following five phases: phase n. 1 – reaction time, phase n. 2 – preparation movements time, phase n. 3 – the first pedal stroke time, phase n. 4 – dead point pedal passage time, phase n. 5 – second pedal stroke time. This is a complicated time-space movement structure whose optimal performance depends especially on the individual's coordination and strength abilities. As was shown by the 3D kinematic analysis, the first, second and fourth phases demand accurate performance of the complex body movements in order to create the optimal conditions for the exertion of the maximum force acting on pedals in the third and fifth phases.

In future studies it would be convenient to combine the kinematographic methods with electromyography which would yield information on the individual muscles engaged in individual phases of the start movement. The results of our research may be used in practice especially by coaches and their riders in their effort to improve the technique of the bicross start during a practice season. Through high-quality analysis an individual technique of a rider may be analyzed in detail, deviations from the ideal technical performance may be revealed or potential mistakes may be identified. It is also possible to compare individual techniques of a number of riders and try to identify the advantages and disadvantages in the technique applied. Other suggestions for future comparative studies may include e.g. an individual rider's differences in performance throughout various practice periods of the year or the technique applied after resuming practice after injury. Due to the lack of relevant literature available to this date it is necessary to further pursue this issue. We believe that in this context our research interest is unique.

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