

Angular Changes in the Elbow Joint During Underwater Movement in Synchronized Swimmers

by

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The aim of the study was to analyze the changes in the projection of the angle between arm and forearm in one cycle of supporting movement of upper limbs in the Vertical and Vertical Bent Knee positions in synchronised swimmers of various sports level. The research material consisted of eight swimmers, three seniors and five juniors. The study was performed using an underwater camera and a computer software. The frequency of images was 50 frames per second. The angular progress of the studied movements in swimmers representing lower level was compared to that of swimmers with higher sport achievements. The duration of phases making up one movement cycle was specified. The scope of angular changes in the joint was calculated as well as the duration of individual phases in one movement cycle, angular velocity of movement in individual phases of the cycle and the degree of asymmetry of the studied movement between left and right limbs was assessed. The course of movement with its phases in the Vertical position was compared with that in the Vertical Bent Knee position. The results of the study made it possible to note the phenomena unnoticed by coaches carrying out visual observation.

The most important ones are omitting, also by experienced swimmers, the phase of water catch, a significant diversity in the course of phase of preparation in terms of symmetry and angular values, large differences in this phase of movement between the Vertical and Vertical Bent Knee positions and low angular velocity in experienced swimmers.

Key words: *synchronized swimming, movement, technique.*

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Introduction

Synchronised swimming is a sports discipline in which competition is based, among other things, on performance of strictly defined combinations of technical elements, called obligatory figures, according to the adopted model. The precision of movement recreation is of fundamental importance for sports performance and is usually closely related to the technique represented by champions of the sport.

According to Starosta (1983) champion technique is achieved after going through three stages: a stage of elementary technique, standard technique and individual technique. There are however few scientific studies using the potential of modern video and computer technology to evaluate this aspects.

For example, in tumbling time angle increases in backward somersaults in athletes of various level of technical advancement have been analysed. According to the authors, thanks to the characteristics of time velocities of joint elbow increases the technique of performing a given movement activity can be precisely specified, and first of all, so called key elements of technique can be isolated (Lojek et al. 2002, Niznikowski et al. 2004).

Similar studies have been conducted in competitive swimming, as shown by works of Martins-Silva et al. (1997 A and B). These authors, however, focused rather on the distribution of velocity in the movement cycle under water, and were less interested in the spatial model of this movement, which may be understandable in competitive swimming.

Hay (1985) dealt with the possibilities of using contemporary audio-video technology. But it was Allinger (1998) who was the pioneer of videorecording and analysis of movement under water in synchronised swimming. His studies related to the comparative analysis of two types of technique of arm movement (Split scull and Double-overhead scull) in the Vertical Spin position.

The aim of this study was to analyse the changes in the front projection of the angle between the arm and forearm in one cycle of movement supporting of upper limbs in the Vertical and Vertical Bent Knee positions in swimmers of various sports level.

Material and Methods

The material for the study consisted of eight synchronised swimmers, three seniors and five juniors. They were deliberately selected to represent various sports levels. All swimmers represent Poland as members of national senior or junior teams and are medallists of Polish championships in their respective age

categories. In the table below the swimmers are presented by sports level on the basis of protocols from competition (table 1).

Table 1*Characteristics of the subjects*

Swimmer	Age (years)	Training history (years) and sports category
Dor champion of effectiveness	22	10 senior
Ag2 model of technique	24	12 senior
<i>Ka2</i>	24	12 senior
<i>Ag1</i>	17	9 junior
<i>Ka1</i>	19	10 junior
<i>Ang</i>	17	8 junior
<i>San</i>	16	7 junior
<i>Zuz</i>	17	7 junior

The underwater part of the Vertical and Vertical Bent Knee positions was filmed with a camera facing the swimmers. The films were then loaded to the computer memory. From each of them one cycle of supporting movement of upper limbs, best performed by the swimmer and best recorded by the camera was selected. The swimmer should perform only this movement during performing obligatory figures in front of the judges. The recorded cycles were analysed using the Avi Image software. The values of projections of joint angle between the arm and forearm were read. This angle is of fundamental importance in the supporting movement of upper limbs and ensures stability, maintaining the balance and appropriate height of position. Changes of the angle in elbow joint, that is the angle between the arm and forearm, determine the effectiveness of this movement most.

The supporting movement in the elbow joint is very complex spatially. It is possible to create a three-dimensional model of the trajectory of selected points of the limb. However, the analysis of the angle projection was considered more valuable, more informative and more valuable in terms of application, and not the actual spatial angle, as the coach can only see the angle projection, and not mathematical and physical values on co-ordinate axes.

Technical parameters of the camera and computer programme make it possible to read fifty frames in each second of movement. This make it possible to calculate the duration of each selected part of movement and the velocity of changes in the angle in the analysed joint.

The supporting movement of upper limbs in the Vertical and Vertical Bent Knee positions is a cyclical movement. Like each cyclical movement and each swimming movement is it divided into two basic phases: the proper phase (called in competitive swimming the paddling phase) and the preparatory phase. In sports swimming, in 1960s the proper phase was divided into more detail phases of water catch, pull, push or other, depending on the author. Cyclical movements typical for synchronised swimming were first divided into detailed phases by Habiera and Rostkowska (2004) (phot. 1).

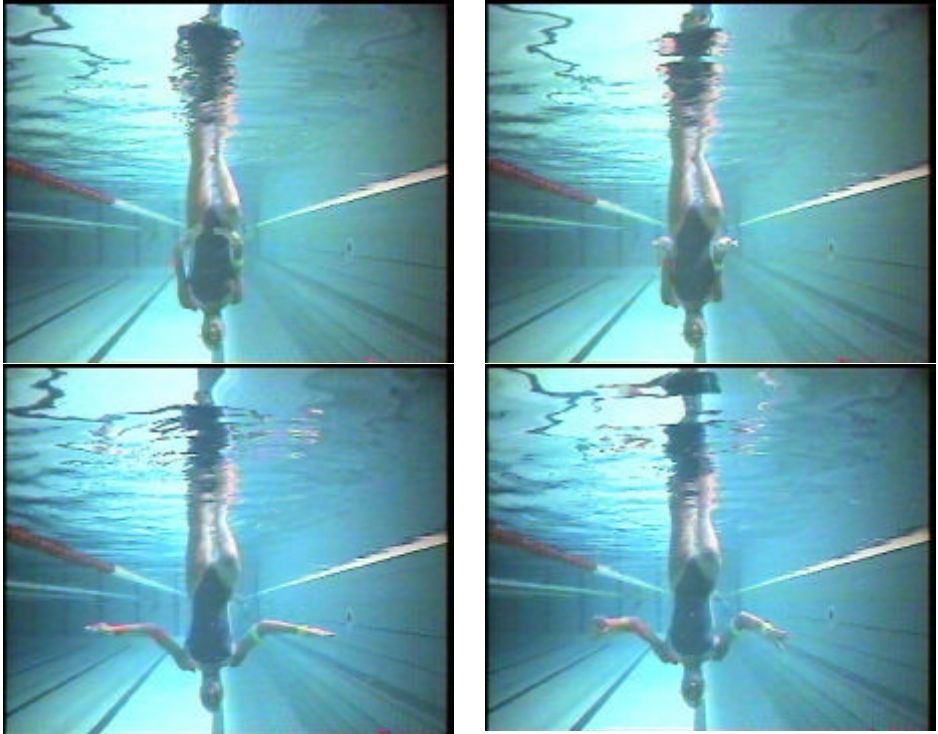


Photo 1 *Positions of upper limbs during phases of underwater movement*

Thus, the following phases of the underwater supporting movement were distinguished:

Phase 1 – water catch, which involves moving forearms so that fingers of both hands meet.

Phase 2 – sweep, from the final moment of the fingers touching to the finishing of turning of the forearm in the elbow joint. There is a slight movement of upper limbs forward.

Phase 3 – pull, which involves a maximum rotation of arms outward while keeping the arm-trunk angle unchanged and at the same time, maximum turning of forearm in elbow joint.

Last, phase 4 – preparatory, is a phase of active rest for the upper limbs, and its beginning is so called „flat”, that is parallel to the water surface, positioning of hands and bringing of tilted arms to the starting position. The duration of the last two phases should be similar with a slight slowing of movement in the preparatory phase.

However, the coaching experience shows that the first two phases of water catch and sweep, are the most important, as they ensure the maintaining of the given position at the appropriate height, and the turned forearm prevents the swimmer from going back during the performance of the discussed position.

Results

The comparison of the studied movements in swimmers on the lower training level to those of swimmers with better sports achievements

The aim of training in synchronised swimming is performance of obligatory figures and positions as closely as possible to the set model. The effects of technical training are assessed by judges. Therefore, both coaches and swimmers are constantly searching for methods and means thanks to which the effectiveness of performance of specific figures will be appreciated by the panel of judges. The main elements assessed by the judges are height, stability and perfection of performance, regardless of the manner of achieving the above elements. Hence, the judges do not check the technique of underwater arm movements used for achieving the set objective. In synchronised swimming, like in each technical sport, there are certain canons of arm movements which are the basis for teaching. The level of sports proficiency allows however for deviation from learned patterns if only a given technique is assessed by the judges as effective.

The technique of swimmer *Dor* who achieved the best sport results, has been considered as the most effective, as using this technique she received the highest notes of all studied girls (table 1). However, in the picture of her technique some individual features have been noted. Thus, it was assumed that this swimmer is the best in the studied group in terms of effectiveness of movement technique. She was called the champion of effectiveness.

The technique of swimmer *Ag2* has been considered to be the best in terms of correctness of movement performance. Thus, it was accepted that this is a model of standard technique, that is the technique according to which less advanced swimmers are trained.

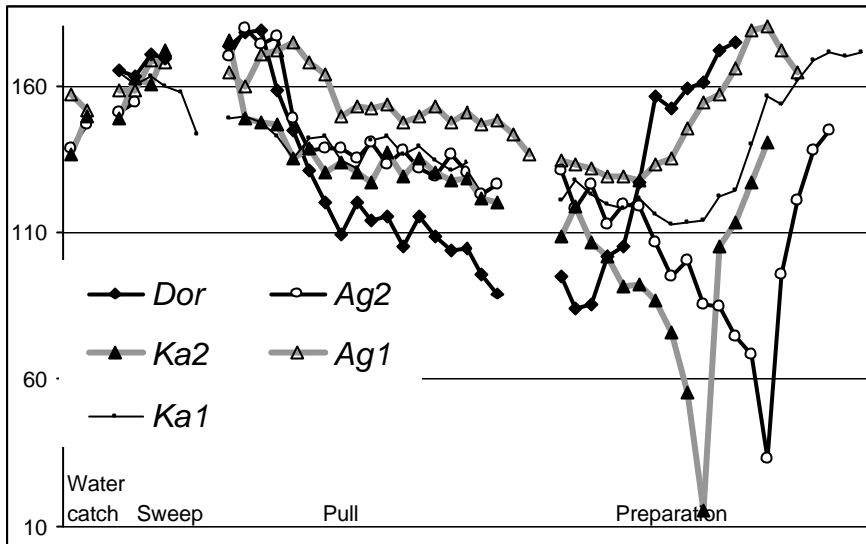


Fig.1. Changes of numerical values of projection of the studied angle of one movement cycle in swimmers Ka2, Ag1 and Ka1 compared to swimmers Dor (champion of effectiveness) and Ag2 (model of technique), left upper limb, Vertical position, degrees

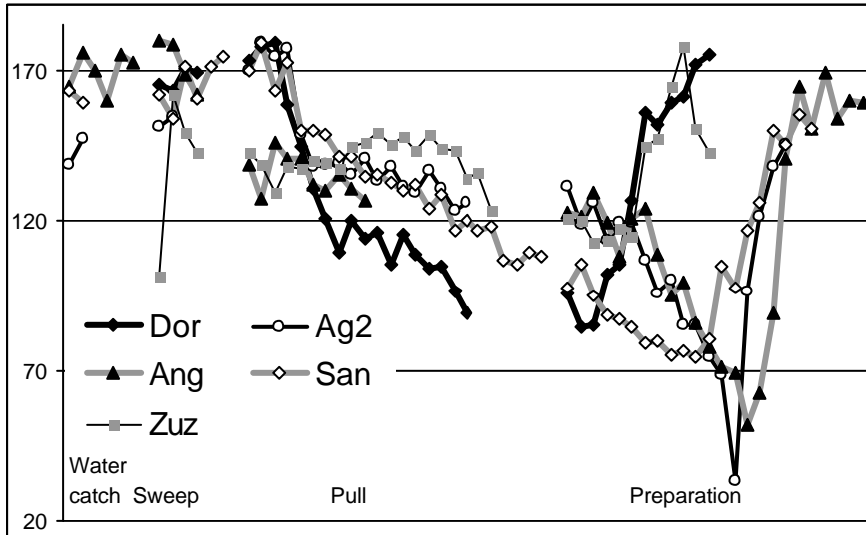


Fig.2. Changes of numerical values of projection of the studied angle during one movement cycle in swimmers Ang, San and Zuz compared to swimmers Dor (champion of effectiveness) and Ag2 (model of technique), left upper limb, Vertical position, degrees

Changes in the projection of the angle between the left arm and forearm in the Vertical position indicate changes between the subjects. Subject *Dor* who has achieved the best sports results does not perform the water catch phase. Similarly, *Ka1* (fig.1) and *Zuz* (fig. 2) omit this phase. The movements of the swimmers *Dor* and *Ag2* considered to be models are similar in the sweep and pull phases, but differ visibly in the preparatory phase. During the preparatory phase some swimmers (*Ag2*, *Ka2*, *Ang* and partly *San*) suddenly lower the value of the angle in question (perform a strong bend in the elbow angle). This is the phase of the cycle during which the largest angular differences between the subjects are noted.

Subject *Ag1* is characterised by the smallest changes in the value of discussed angle during the whole movement cycle.

Duration of phases making up one movement cycle

The duration of the movement cycle is shortest in the most effective swimmer *Dor* (0.68 second) and longest in junior *San* (1.04 second). In other subjects the duration is approximately 0.8 s and that is the time of performance of the cycle by subject *Ag2* considered to have the model technique (table 2). The phases of water catch and sweep are short, from 0.04 s to 0.12 s, which is 3.9% to 14.4% of the whole cycle (table 3). The phase of pull is longer than the preparatory phase in five out of eight subjects, including subject *Dor* with the best sports results. In the model technique of subject *Ag2* the duration of pull and preparation is the same. In two studied juniors, *Ka1* and *Ang*, the preparation is much longer than the pull.

Table 2

Duration of the cycle and its phases on the example of angular changes in the right and left elbow joints, Vertical, in seconds

Swimmer	<i>Dor</i>	<i>Ag2</i>	<i>Ka2</i>	<i>Ag1</i>	<i>Ka1</i>	<i>Ang</i>	<i>San</i>	<i>Zuz</i>
Phase of cycle								
Water catch	0.00	0.04	0.04	0.04	0.00	0.12	0.04	0.00
Sweep	0.08	0.04	0.08	0.08	0.12	0.08	0.12	0.08
Pull	0.36	0.36	0.36	0.40	0.32	0.20	0.48	0.40
Preparation	0.24	0.36	0.28	0.32	0.40	0.48	0.40	0.24
Duration of the whole movement cycle	0.68	0.80	0.76	0.84	0.84	0.88	1.04	0.72

Table 3

Normalised time [%] of phases of supporting movement of upper limbs in the Vertical position

Swimmer	<i>Dor</i>	<i>Ag2</i>	<i>Ka2</i>	<i>Ag1</i>	<i>Ka1</i>	<i>Ang</i>	<i>San</i>	<i>Zuz</i>
Phase of cycle								
<i>Water catch</i>	0.0	5.0	5.3	4.8	0.0	13.6	3.9	0.0
Sweep	11.8	5.0	10.5	9.5	14.3	9.1	11.5	11.1
Pull	52.9	45.0	47.4	47.6	38.1	22.7	46.2	55.6
Preparation	35.3	45.0	36.8	38.1	47.6	54.6	38.4	33.3

Comparison of changes in the discussed angle and duration of phases between the Vertical and Vertical Bent Knee positions

For comparison of the course of the movement cycle between the Vertical and Vertical Bent Knee positions three seniors were selected: *Dor*, *Ag2* and *Ka2* (Fig.3)

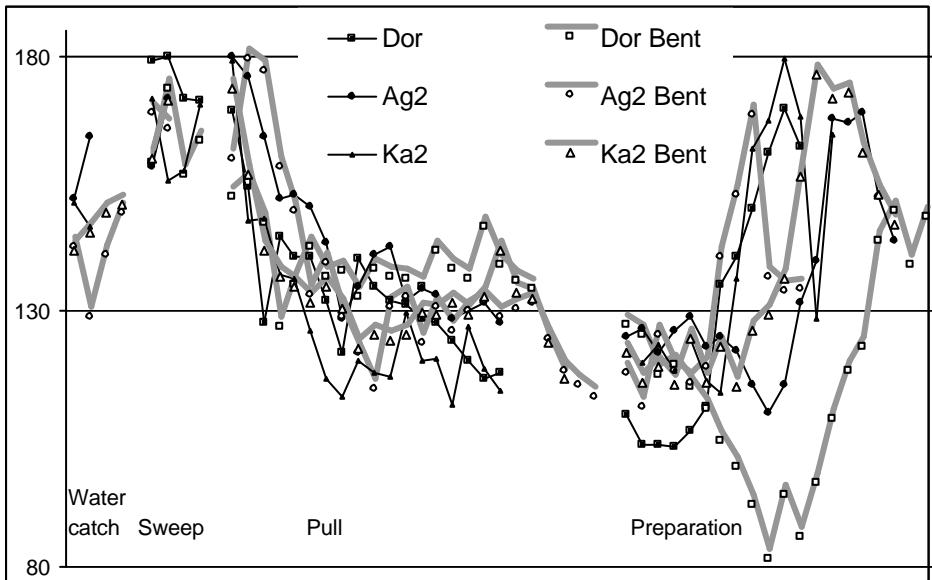


Fig. 3. Comparison of angles during the performance of the Vertical and Vertical Bent Knee positions in the three best swimmers

In the Vertical Bent Knee position the bending of the knee and hip creates different conditions of movement. Thus, it would seem that the supporting movements of upper limbs should differ between these positions. However, the

comparison of angular changes in the three best swimmers indicates that in the sweep and pull phases the course of movement is very similar (fig. 3), in the preparatory phase only the movement of swimmer *Dor* differs from the other subjects. Some slight differences can be noted in the phase of water catch in swimmers *Ag2* and *Ka2*. In both positions this phase was not performed by *Dor*. The duration of water catch and sweep phases in the Vertical Bent Knee positions is the same as in the Vertical position. The phases of pull and preparation in the Vertical Bent Knee position are longer by approximately 0.04-0.16 second which results in slight extending of the duration of the whole movement cycle in this position.

Range of angular changes in the joint

Phases of water catch and sweep

The phase of water catch was not performed by all swimmers. If it occurred then it was very short. In the Vertical position in the water catch phase the front angle projection for left limbs ranged from 137° to 176° with $\bar{x} = 158.6^\circ$ and for right limbs more – from 146° to 180° with $\bar{x} = 165.9^\circ$. The right limbs worked with a smaller bending of the elbows, also in the sweep phase (Table 4). In the water catch and sweep phases the angle in some swimmers decreased and increased or changed irregularly in others.

Table 4

Range of changes in angle in the elbow joint in short phases, water catch and sweep

Phase of cycle	Vertical position							
	left limbs				right limbs			
	\bar{x}	SD	min	max	\bar{x}	SD	min	max
Water catch	158.6	12.7	137	176	165.9	10.7	146	180
Sweep	160.4	13.7	101	180	171.4	7.6	156	180
	Vertical Bent Knee position							
Water catch	136	20.5	116	180	154	13.7	128	178
Sweep	155	21.5	122	180	166	6.3	150	175

Phases of pull and push

In the longer phase of pull (table 5) the front angle projection decreased quite evenly for the whole duration of the phase, and in the preparatory phase the studied angle first decreased significantly until it reached a minimum, and

then increased to reach values necessary to start a new movement cycle, that is similar to the beginning of the water catch phase.

Table 5*Arithmetic means of angles in long phases, pull and preparation*

Phase of cycle	Vertical				
	limbs	initial value	max	min	final value
Pull	left	160	166	120	120
	right	170	171	124	127
Preparation	left	116	164	77	156
	right	121	174	98	163
Vertical Bent Knee					
Pull	left	160	176	127	129
	right	166	174	128	129
Preparation	left	123	156	82	145
	right	126	164	98	147

Angular velocity of movement in individual phases of the cycle

The technical parameters of the camera and the computer programme make it possible to obtain fifty images per second. Thus, it may be assumed that a section of movement recorded in one picture lasts 0.02 second. This makes it possible to calculate with high accuracy the velocity of angular changes in the joint. The results of these calculations are given in values of angle change in 0.01 second (table 6). Visually the angular velocity may be followed by observing the distances between markers in diagrams. A large distance between markers indicates high angular velocity of the movement and the other way round, a small distance between the markers indicates low angular velocity. Also a rise of the line in the diagram indicates an increase in the value of the angle from image to image, and lowering of the line – the decrease of the angle. The angular velocity is a result of accelerated motion at one point, and retarded motion at another point. This indicates an uneven movement.

The results of the study indicate that in swimmers of higher sports level the changes in the studied angle projection are slower. Taking into account the swimmers on a higher sports level it may be noted that the angular velocity is greatest during the preparation and smallest during the sweep. The mean angular velocity of the whole movement cycle without division into phases was

not studied, assuming that a swimmers mastery is the ability to differentiate the velocity depending on the cycle phase.

Table 6

Arithmetic means of angular velocity in individual phases of cycle in swimmers of the highest and lowest angular velocity in a given phase (mean change of angles in 0.1 s, left limbs, vertical, in degrees)

Phase of cycle	smallest of the subjects	model Dor and Ag2	greatest of the subjects
Water catch	Ag1 31	Dor no phase, Ag2 35	San 44
Sweep	Ag2 18	Dor 25 Ag2 18	Zuz 152
Pull	Ka1, Zuz 21	Dor 40 Ag2 35	Ang 41
Preparation	Ag1 24	Dor 48 Ag2 70	Ka2 90

Assessment of the degree of symmetry of the studied movement

In the Vertical position in the swimmer *Dor* quite a consistent angular course of the movement on the left and right is noted and in swimmer *Ag.2* There is a sudden decrease in the studied angle in the movement of the right limb in the preparatory phase (fig. 4).

The swimmer *Ka2*, the third of the seniors, also suddenly decreases the angle of the left limb in the preparatory phase. In the weakest of the juniors, *Zuz*, the movement is symmetrical (fig. 5).

In the Vertical Bent Knee position in the preparatory phase all three seniors visibly decreased the value of the angle of the left arm compared to the right, that is displayed a great asymmetry (fig. 6). In all five juniors there is no visible asymmetry between left and right limbs, as presented in fig. 7.

The observed phenomenon shows that seniors compensate asymmetrical position of lower limbs with asymmetrical movements of upper limbs in the preparatory phase.

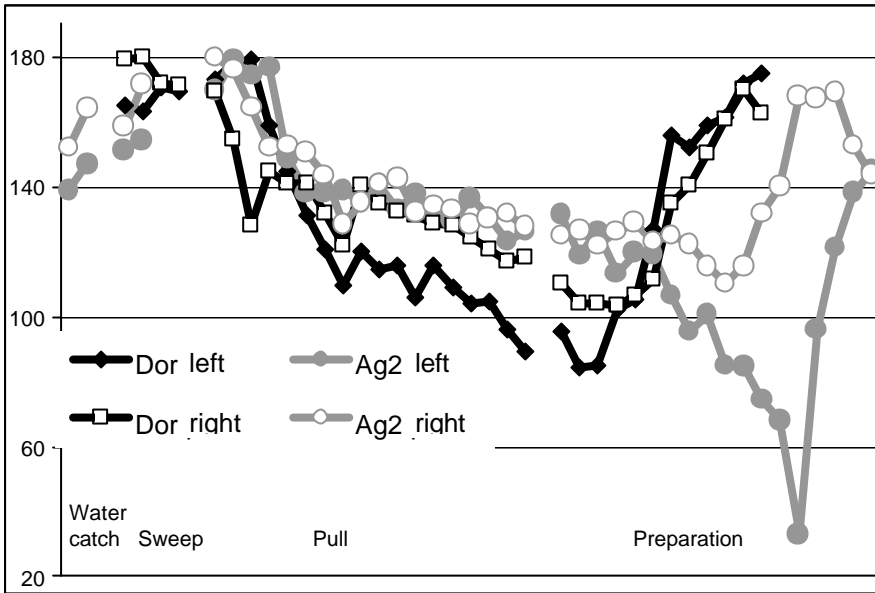


Fig. 4. Degree of symmetry that is a comparison of changes in angles of the upper right and left limbs in swimmers considered to be model, Dor and Ag2, Vertical position

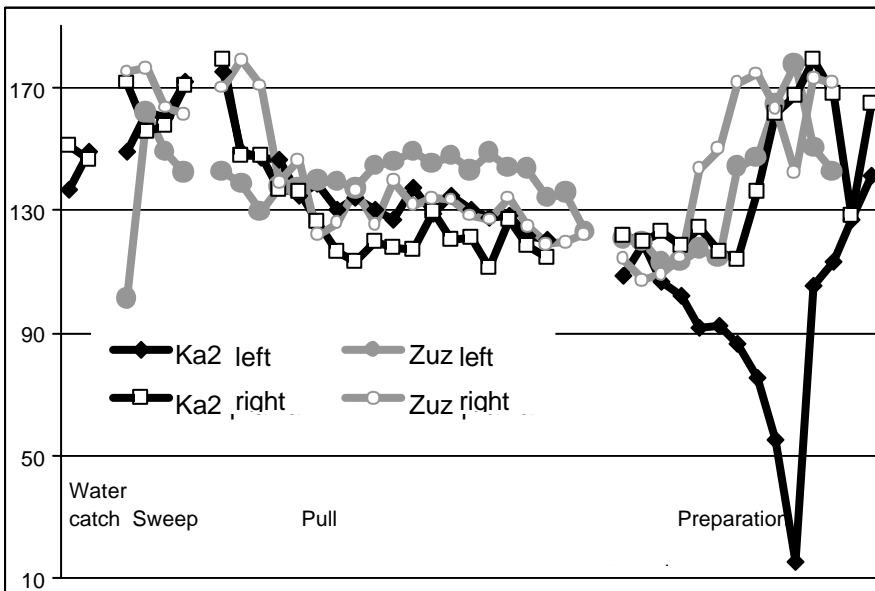


Fig. 5. Degree of symmetry that is comparison of changes in angles of the upper right and left limbs in swimmers Ka2 and Zuz, Vertical

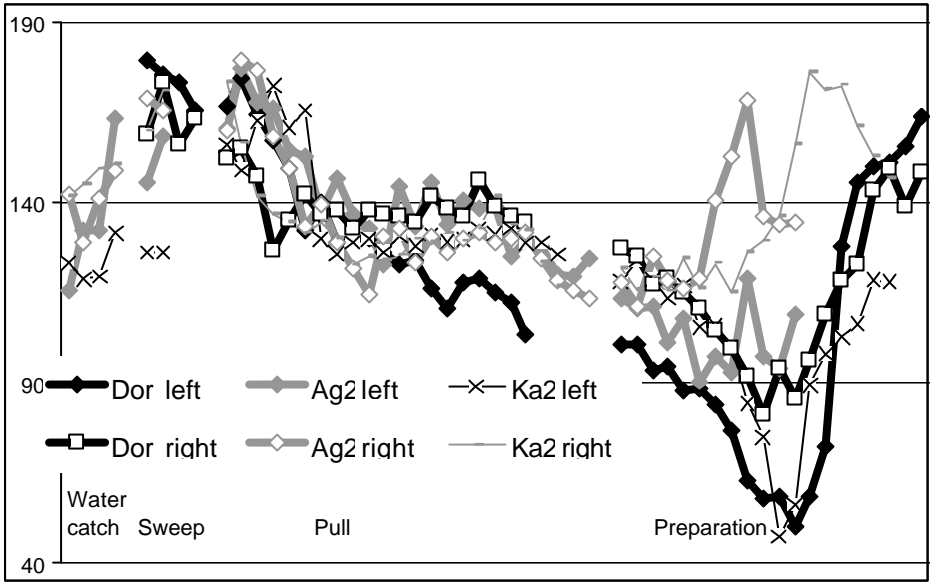


Fig. 6. Degree of symmetry that is comparison of changes in angles of the upper right and left limbs in swimmers Dor, Ag2 and Ka2, Vertical Bent Knee

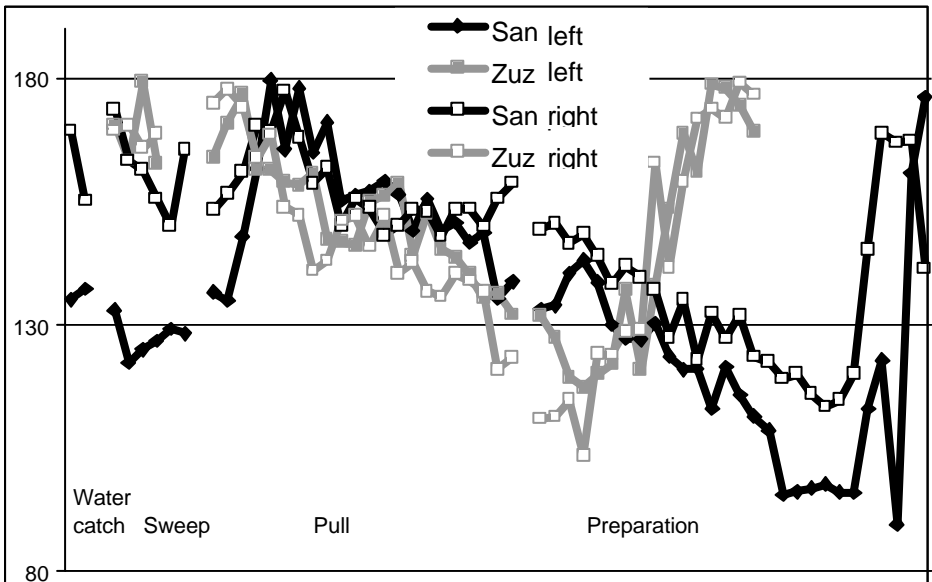


Fig. 7. Degree of symmetry that is a comparison of changes in angles of the upper right and left limbs in swimmers San and Zuz, Vertical Bent Knee

Discussion

The use of an appropriate research apparatus made it possible to carry out very detailed observations and then an analysis of technique of underwater movements. Thanks to it the unexpected phenomenon of omitting the seemingly most important phase (water catch) by the swimmer considered to be the champion of effectiveness was noticed.

On the basis of the obtained results the model of technique of underwater movements of arms can be definitely determined which is extremely important for coaching and swimming practice. For the judge assessment of the technique of the arm movement in positions and figures does not matter, unlike its effectiveness. The analysis shows also that the course of individual phases of movement, both in time and in space, is very similar. The greatest diversity is noted in the last phase – the preparatory phase. In most swimmers this phase is longest. The angular velocity is similar in swimmers of the higher sports level, and differs slightly in the remaining swimmers. The duration of phases, as well as the whole movement cycle, is shortest in the swimmer considered to be the champion of effectiveness. However, in the swimmer whose movement technique is considered model, the duration of phases is within arithmetic mean.

In the analysis of symmetry (left-right) of movements performed in individual positions it turns out that in the Vertical position the underwater arm movements are symmetrical. In the Vertical Bent Knee position, however, asymmetry is observed. The movement of the arm on the side of the bent lower limb shows an increase in angular velocity and thus greater bending in the elbow joint. This results from asymmetry of the position itself and this dependence is logical and correct. However, the degree of asymmetry is visibly greater in swimmers of the higher level of sports training.

All results obtained with the use of the research method used in this study are innovative, therefore it is impossible to compare them with results of other studies. Further research should relate to the observation of changes taking place in the technique of arm movement during training as well as optimisation of the training process and mastering of the technique in long-term training plans.

Conclusions

1. On the basis of video-computer analysis of the underwater arm movement in synchronised swimming the components of the movement technique can be assessed which significantly facilitates their teaching and mastering.

2. Arm movements performed underwater should be carried out according to the set phases and be characterised by differentiated velocity in individual phases.
3. In swimmers with better sports achievements lower angular velocities in the studied joint are observed which is an effect of smaller angular changes during the movement. This small angular changability seems to be a feature of technique on a higher level.
4. The asymmetry in the arm movements in the Vertical Bent Knee position is definitely greater in swimmers on a higher level of sports training. It can be assumed that it results from the balancing of the asymmetrical position of the lower limbs. This observation is a valuable tip for coaches.
5. Juniors who want to match swimmers with better abilities should strive to shorten the duration of the whole movement cycle. Only the swimmer *Zuz* should verify the course and proportions of all cycle phases.
6. Unexplained issues which require further study are a lack of phase of water catch and large diversity between the preparatory phase of the subjects.

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