**Research article**

# Searching for criteria in evaluating the monofin swimming turn from the perspective of coaching and improving technique

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**Abstract**

This study aims to analysise the selected kinematic parameters of the monofin swimming turn. The high complexity of performing turns is hindered by the large surface of the monofin, which disturbs control and sense of the body in water. A lack of objective data available on monofin swimming turns has resulted in field research connected with the specification of parameters needed for the evaluation of the technique. Therefore, turns observed in elite swimmers contain underlying conclusions for objective criteria, ensuring the highest level of coaching and the improving of turns in young swimmers. Six, high level, male swimmers participated in the study. The subject of the analysis was the fastest turn, from one out of three trial turns made after swimming a distance of 25 m. Images of the turns were collected from two cameras located under water in accordance with the procedures of the previous analyses of freestyle turns. The images were digitized and analysed by the SIMI®- Movement Analysis System. The interdependency of the total turn time and the remaining recorded parameters, constituted the basis for analysis of the kinematic parameters of five turn phases. The interdependency was measured using r-Pearson's correlation coefficients. The novel character of the subject covered in this study, forced interpretation of the results on the basis of turn analyses in freestyle swimming. The results allow for the creation of a diagram outlinig area of search for an effective and efficient monofin swimming turn mechanism. The activities performed from the moment of wall contact until the commencement of stroking seem to be crucial for turn improvement. A strong belief has resulted that, the correct monofin swimming turn, is more than just a simple consequence of the fastest performance of all its components. The most important criteria in evaluating the quality of the monofin swimming turn are: striving for the optimal extension of wall contact time, push-off time and glide time.

**Key words:** Monofin, turn, kinematics, technique evaluation.

## Introduction

The technique of monofin swimming consists of the oscillatory movements of the trunk and legs in the sagittal plane, while in a prone position. The scope of movement increases, from the shoulders in the direction of the centre of the swimmer's mass and feet, which transfer torque to the monofin's surface. This being approximately twenty times greater than on the surface of feet, producing propulsion, in swimming without fins. The dimension of the monofin and the structure of the swimming movements are the reasons why average speed in monofin swimming exceeds the speed of crawl swimming by approximately 24%, on average over a 50m

distance, and by approximately 7%, over a 1500m distance.

The swimming result consists of the start, the covering of distance and the turn. The analysis of monofin swimming technique focuses on establishing its evaluation criteria as per kinematics, (Gautier et al., 2004; Rejman et al., 2003; Shuping, 1989; Tze Chung Luk et al., 1999), dynamics (Rejman, 1999), and modelling (Rejman and Ochman, 2007; Wu, 1971). The specific character of monofin swimming also constitutes the basis for interpretation of mechanisms explaining the nature of locomotion in water (Arellano, 1999; Colman et al., 1999; Ungerechts, 1982). The lack of an objective analysis of monofin swimming turn results in the undertaking of studies on the issue of technique evaluation. At the same time, the novel character of the research undertaken, calls for interpretation of the results obtained on the basis of the analysis of freestyle turns.

It is assumed that the structure of the turn technique in monofin swimming does not differ much from the turn technique in freestyle swimming (Figure 1). Consequently, there is the same phase division in both types of turn: swimming-in, rotation, wall contact, push-off, glide and commencement of stroking (Costill et al., 1992). The total turn time in freestyle swimming is approximately 8 sec. In monofin swimming the total turn time is shorter. Within the space of a few seconds the swimmer must (apart from swimming-in and swimming-out from the wall) make a rotation around the transverse axis, push off the wall and turn the body around the longitudinal axis during the impulse and first meters of the gliding phase. The large surface of the monofin additionally hinders the control of the sense of body in the space. The high complexity of a turn, which is to be made in a relatively short time, requires the full automation of movements by the swimmer. It has been well proven that the correct turn may help in improving the results of swimming performance. Assuming that the turns take approximately 36% of freestyle race time in a short course (Thayer and Hay, 1984), and 31% in a 50m pool (Arellano et al., 1994), it has been proven that the reserve gained due to correct turns, results in a clear difference in preformance time. The time needed to cover the distance of 1500m in 50m-long pool (29 turns), may be reduced by even 5.4 sec. (Chow et al., 1984).

Within the scope of the arguments formulated, there is a well-grounded need to specify factors determining the quality of the monofin swimming turn. Therefore the aims of this study have been formulated in a direction outlined by the analysis of the chosen kinematic
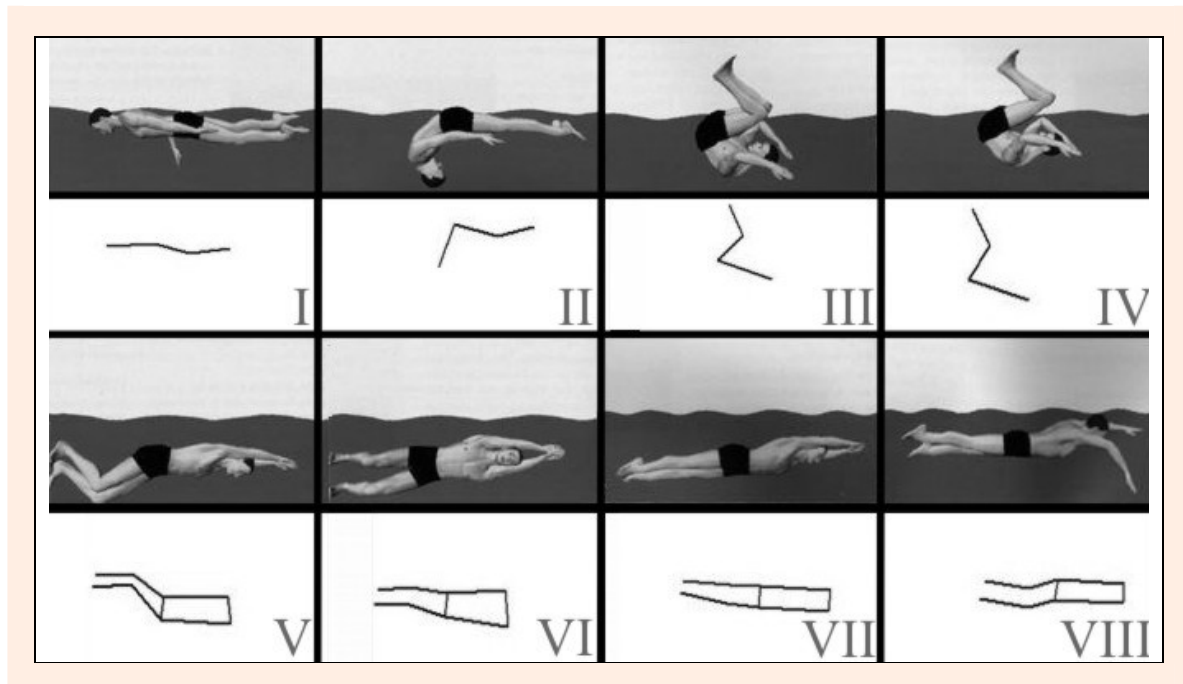
**Figure 1.** **The illustration of assumption that the structure of the turn technique in the monofin swimming does not differ much from the turn technique in freestyle swimming. The particular phases of freestyle (Ungerechts, 2002) and monofin (stick figure) were compared: swimming-in (I), rotation (II,III,IV), push-off (V,VI) glide (VII) and commencement of stroking (VIII).**

parameters of the monofin turn. A biomechanical analysis served to formulate the criteria for turn quality in respect to its efficiency, measured through minimizing the performance time of the turn. Generalisation of the obtained results allowed creation of a diagram describing the basic contributing factors to turn technique in monofin swimming. The awareness of objective assessment of turn technique elements is essential in order to precisely formulate the goal of learning and perfecting this important element of swimming performance. The subject of analysis in this study is the turn technique performed by swimmers of the highest level, and the results obtained

are a source of information for facilitating a training process, which can then be addressed to swimmers at a lower stage of their sporting career. Within the context presented, the didactic aspects of this study, by realization of the aims of the application, dominates the sporting aspects outlined through the realization of typical cognitive aims. Information obtained in this way, should establish areas of search regarding a mechanism for effective and efficient monofin swimming turns. Thus, this information provides basis for more detailed description of the turn evaluation criteria in the future.
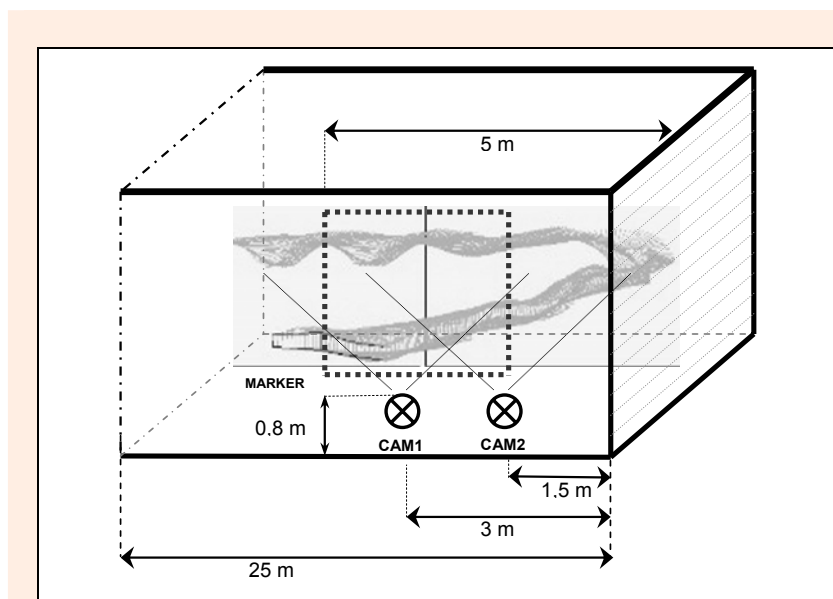


**Figure 2.** **The cameras arrangement and schema for equipment set-up The stick figures diagram is inserted in the schema.**
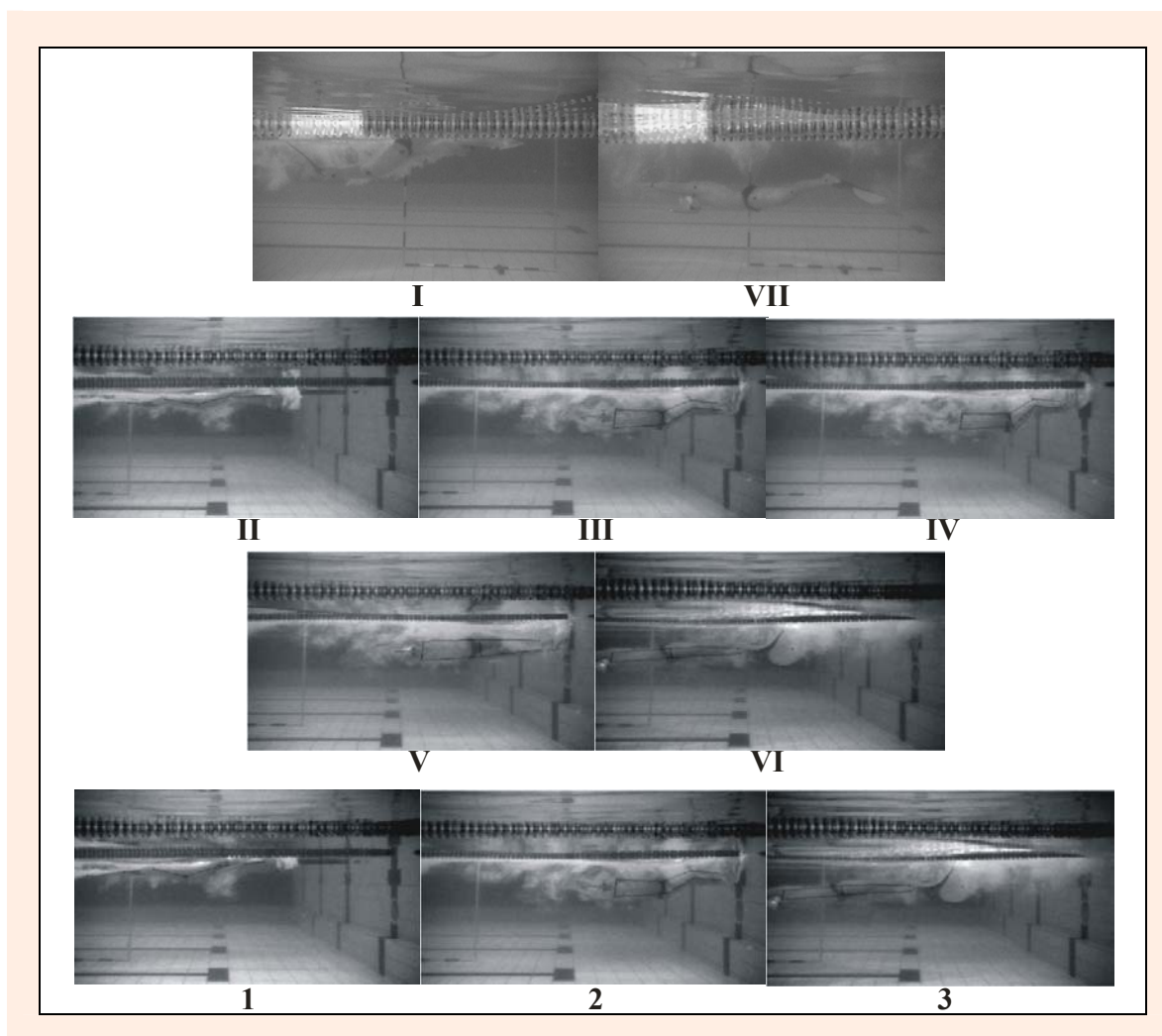
**Figure 3. Illustration outlining temporal parameters of the fin swimming turn, based on division into phase and sequence.**

## Methods

Six male swimmers - members of the Polish Monofin Swimming Team -volunteered for the study. The average age of the participants was $17.2 \pm 1.2$ and they constituted a homogeneous group as per their somatic construction (average body mass – $76.33 \pm 6.25$; average body height – $1.84 \pm 0.04$). All the subjects represented the highest international level. In a manner similar to the experiments carried out in the research on freestyle turns (e.g. Blanksby et al., 1995), the research task consisted of three trial turns after swimming 25m. An analysis was made on one turn performed by each swimmer. This turn was selected based on the shortest total turn time. The swimmers were instructed to put maximum effort, into both the swimming speed and the speed of performing the turn.

The turns were recorded by two digital video cameras placed under water (Figure 2). One camera was located at a distance of 1.5m from the wall, the other at a distance of 3m from the wall. The locations of the cameras were chosen in such a manner, as to allow for setting the axes of the cameras, perpendicular to the objects filmed, in the crucial fragments of the turns. Both cameras covered a common field of view (and common markers) in order to fulfil the rules of image calibration and synchronization in time and space. Markers, allowing for the tracking of relocation of particular segments of the body, were applied to the bodies of the subjects. The points were located on both sides in the axes of the ankle, knee, thigh and shoulder joints (Plagenhoef, 1971). The distal part of the foot was also marked. The turns were analyzed in two dimensions as is a standard in the analysis of monofin swimming technique (Rejman, 1999). The filming procedure was in accordance with the experiments carried out by other authors and applied repeatedly for analyses of turns in freestyle swimming (e.g., Blanksby et al., 1996a; 1996b; Mason and Pilcher, 2002; Takahashi et al., 1983). The video material was obtained at a frequency of 50 Hz. The samples were analyzed based on digitaization of image, using the SIMI®-Germany system of movement analysis. The procedure for recording video material and its analysis was in accordance with the ISO 9001 standard (Figure 3).

Based on the research expirience of freestyle turns, the most important parameters of the monofin swimming turn were chosen for the analytic purposes (Tables 1, 2) The subject of the analyses were the kinematic parameters of five phases of a turn: swimming-in, rotation, push-off, glide and commencement of stroking (Costill et al., 1992). For the sake of the didactic purposes of this study, the following parameters of the turn were measured and analysed: the Tuck Index (defined as the minimum

**Table 1. Specification and description of the temporal parameters in fin swimming turn technique, recorded and analyzed during the research.**

| Total Turn Time (Figure 2. I-VII) Time period from the moment when the hip joints swim trough the point placed 5m from the wall before turning, till the moment when the hip joints swim trough the point placed 5m from the wall after turning. | Swim-in Time (Figure 2. I-II) Time period from the moment when the hip joints swim trough the point placed 5m from the wall before turning, till the moment of the turning initiation (downward movement of the shoulder). | Rotation Time (Figure 2. II-III) Time period from the moment of the turning initiation, till the moment when the turning is finished (first moment of the feet contact with the wall). |
|---|---|---|
| **Wall Contact Time** (Figure 2. III-V) Time period from the moment of the first feet contact with the wall, till the moment when the feet lost contact with the wall. | **Push-off Time** (Figure 2. IV-V) Time period between the moment when the hip joints forward displacement is initiated after contact with the wall, and the moment when the feet lost contact with the wall. | **Glide Time** (Figure 2. V-VI) Time period between the moment when the feet lost contact with the wall, and the moment of the knee joints extension. |
| **Commencement of Stroking Time** (Figure 2. VI-VII) Time period between the first propulsive movements initiation (the knee joints extension), and the moment when the hip joints swim through the point placed 5 m from the wall after turning. | | |
| **Time In** (Figure 2. 1-2) Time period from the moment when the head moves through the horizontal line initializing the turning, till the moment of the first feet contact with the wall. | **Time Out** (Figure 2. 2-3) Time period from the moment of the first feet contact with the wall, till the moment when the head moves back to the horizontal line after the turning. | **Turn Time** (Figure 2. 1-3) The sum of the Time-in and time-out. |

distance of the hip joint from the wall during foot contact, expressed as a percentage of leg length -trochanteric height - (Table 3). This index describes the degree of maximum tuck - the degree of leg flexion just before the push-off is beginning. The larger the tuck index (straighter legs), the faster the turn time will be assessed (Blanksby et al., 1996a). It also describes the angle of knee joint flexion during performing the index metnined, push-off angle and glide angle (Table 3). The average velocities of particular turn phases were calculated as derivatives of distance and time.

A distance of 5 m (Figure 2) from the swimming pool wall was assumed as the turn distance (Blanksby et.al., 1996a; 2004; Newble, 1982; Takahashi et.al., 1983). The high diagnostic value of the total turn time for evaluation of technique was emphasized in the studies cited. Therefore, the monofin swimming turns were analyzed from the vantage point of interdependences taking place between the total turn times and remaining recorded parameters. The r-Pearson's correlation coefficient was used as the measure of listed interdependences. The r-Pearson's correlation coefficient is a statistical tool used

in the procedures of establishing quality parameters in freestyle turns (e.g. Blanksby et al. 1996a; Mason and Pilcher, 2002). The level of significance was established as $p = 0.05$. For the observed random sample (n = 6 elements) critical value r-Pearson ($r_{0.05}$) is 0.7 [established on the basis of the Student test for degrees of freedom = 4 (n-2)].
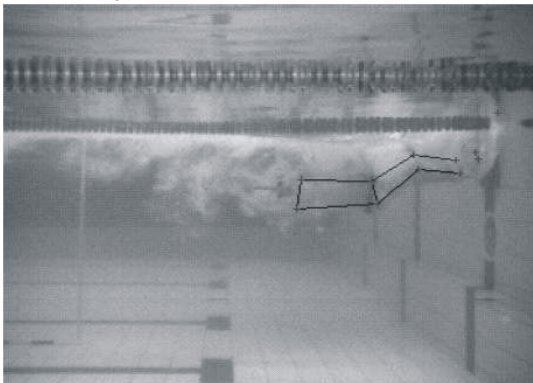
## Results

The results presented in Table 4 indicate similarities in technique of monofin swimming turns and freestyle swimming turns. The differences in performing the compared turns relate to neither the average push-off velocity, nor to push-off depth nor to flexion of leg segments at the moment of initiating the push-off (Tuck Index and angle in the knee joint) nor to the absolute time-in nor to the absolute time-out. The similarities presented here suggest that the results supplemented by data obtained from the analyses of freestyle swimming turns, constitute the basis for objective evaluation of the monofin swimming turn technique.

**Table 2. Specification and description of the distance and depth parameters in fin swimming turn technique, recorded and analyzed during the research.**

| Swim-in Distance Distance between the distal part of the hands and the wall at the moment of the turn initiation | Push-off Distance The distance of the hip joints displacement between the moment of initiation of the hip joints forward movement and the moment when the feet lost contact with the wall. | Glide Distance The distance of the hip joints displacement between the moment when the feet lost contact with the wall, and the moment of the first propulsive movement initiation. |
|---|---|---|
| **Surfacing Distance** The distance of the hip joints displacement between the moment when the feet lost contact with the wall, and the moment of the surfacing. | **First Propulsive Movements Distance** The depth of immersion of the hip joints at the moment of the knee joints extension begins after push-off. | **Turn Distance** The distance of the hip joints displacement from the moment of the turn initiation till the moment when the feet lost contact with the wall. |
| **Push-off Depth** The depth of immersion of the hip joints at the moment when the feet lost contact with the wall | | |

**Table 3.** Specification and description of the parameters of the body segments mutual displacement in fin swimming turn technique, recorded and analyzed during the research.

| Tuck Index | Max Knee flexion |
|---|---|
| Point when the hip was at its minimum distance from the wall during foot contact and was expressed as a percentage of the trochanteric height | Angle of the knee flexion at the moment of Tuck Index estimation |
| | **Push-off Angle** |
| | Angle between the longitudinal axis if the swimmer's body and the horizontal line at the moment when the feet lost contact with the wall. |
| | **Glide Angle** |
| | Angle between the longitudinal axis if the swimmer's body and the horizontal line at the moment of the knee joints extension begins after push-off. |

The diagram presented in Figure 4 is adapted from Hay's (1992) traditional deterministic model of turning. Therefore it should be a source providing information underlying the search for core criteria in determining an efficient and effective mechanism for the monofin swimming turn. The interpretation of the diagram is based on the analysis of the statistical significance of relations between the total turn time and the parameters studied, which constitute its construction. Thanks to this, there is the possibility to select factors which may be assumed as criteria for evaluation of monofin swimming turn technique.

The values of the correlation coefficients possessing the statistical significance level ($r \geq 0.9$) indicate that the minimization of swim-in time, the minimization of the commencement of stroking time and the extension of the duration of wall contact, are the most significant factors responsible for reducing the total turn time. A significant role ($r \geq 0.7$) is played by the necessity to initiate the push-off with the larger Tuck Index and maximalisation
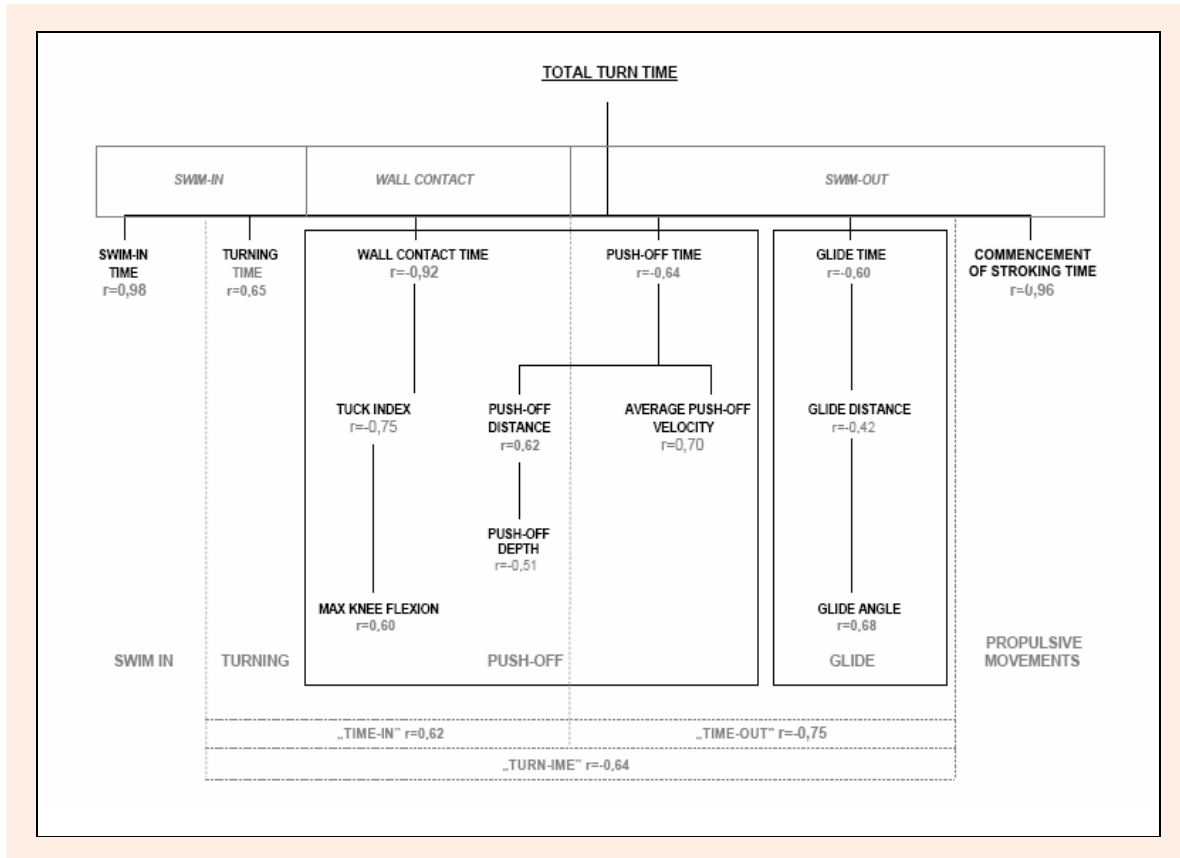


**Figure 4.** The diagram illustrated the basic contributing factors in turn technique in monofin swimming with the values of the Pearson's correlation coefficients calculated between the analyzed factors and the total turn time. For the demonstrative purposes the diagram is set in the divisions of the turn technique structure.

**Table 4.** The comparative specification of the average values of parameters acknowledged as decisive in the evaluation of the fin swimming turn technique with analogous parameters collected as a result of studies on the freestyle turn technique.

| PARAMETERS | CURRENT STUDY | | STUDY OF THE FREE STYLE TUMBLE TURN * AVERAGE VALUES | | | |
|---|---|---|---|---|---|---|
| | $\overline{X}$ | SD | | | | |
| **Total Turn Time** | 5.10 | .51 | 7.26 *(6)* | 8.53 *(3)* | 7.63 *(7)* | 8.22 *(2)* |
| **Swim-in Time** | 1.70 | .25 | 2.35 *(10)* | | | |
| **Wall Contact Time** | .20 | .03 | .38 *(6)* | .35 *(7)* | .29 *(8)* | .36 *(11)* |
| **Push-off Time** | .11 | .04 | .22 *(9)* | .218 *(1)* | | |
| **Commencement of Stroking** | 1.88 | .36 | .55 *(5)* | | | |
| **Push-off Distance** | .36 | .20 | .46 *(3)* | | | |
| Av. Push-off Velocity | 2.66 | .69 | 1.95 *(3)* | 2.58 *(2)* | | |
| **Push-off Depth** | .37 | .11 | .35 *(10)* | .5 *(9)* | .4 *(7)* | |
| Tuck Index | .73 | .25 | .6 *(6)* | | | |
| **Glide Angle** | 18.50 | 6.12 | No data | | | |
| Rotation Time | 1.01 | .10 | .7 *(1)* | | | |
| **Max Knee Flexion** | 89.42 | 10.97 | 90 *(10)* | 60 *(11)* | | |
| **Glide Time** | .29 | .07 | .55 *(5)* | | | |
| **Glide Distance** | .68 | .21 | 1.35 *(7)* | | | |
| Time-in | .99 | .11 | 1.27 *(4)* | | | |
| **Time-out** | 1.79 | .47 | 2.08 *(4)* | 1.80 *(2)* | | |
| **Turn Time** | 2.78 | .44 | 3.15 *(4)* | | | |

The marks of reference to the source works are given in brackets, in italics. *(1)* Blanksby et al., 2004; *(2)* Clothier et al., 2000a; *(3)* Clothier et al., 2000b; *(4)* Blanksby et al., 1995; *(5)* Hay, 1986; *(6)* Hodgkinson and Blanksby, 1996; *(7)* Cossor et al., 1999; *(8)* Lyttle and Mason, 1997; *(9)* Lyttle et al., 1999a; *(10)* Lyttle et al., 1998; *(11)* Takahashi et al., 1983.

\*All of the parameters of freestyle turn technique were collected on the 5m distance-in and 5m distance-out.

of push-off velocity. Within the group of factors, indicating correlations accepted as significant for implementation of the research objectives, (r = 0.60 ≥ 0.69) were: rotation time, parameters describing the structure of push-off (time and distance), the structure of the glide (time and angle of glide) and the angle of knee joint flexion at the moment of establishing the Tuck Index. In addition, little diagnostic value was attributed to interdependences relating to the push-off depth and glide distance (r = 0.4 ≥ 0.6).

A quantitative analysis of the diagram discussed indicates that the role played by particular phases in performing correct turns in monofin swimming. The most numerous group of factors significant for reducing the total turn time are: parameters describing push-off technique, followed by glide phase parameters, then swimming-in parameters and finally one parameter describing commencement of stroking.

## Discussion

Comparing the values of the kinematical parameters of both the freestyle turn and the monofin turn (Table 4), allows for an objective indication of similarities in both turn movements structures, visible in figure 1. The common objective elements in the turn structures are a starting point for discussion on the criteria of monofin turn quality. Table 4 contains the values of the parameters of freestyle and monofin turns registered at 5m distance from the wall. The set-up applied does not allow for the analysis of a complete turn in the understanding of the phase division presented above. Turn recording was finished at the commencement of the stroking phase (5m from the wall). This fact does not influence the diligence of both turns comparison. For at a distance of 5m the same movements take place connected with the turn action (e.g.: push-off or glide) as are observed when the turn

distance is 7.5m. Therefore in the comparative set-up (Table 4) the results based on registering turn parameters at the 7.5m distance have been omitted. Particularly that there exist numerous freestyle turn analyses based on a 10m (in and out) turn distance measurement (Blanksby et al., 1996a; 2004; Clothier et al., 2000a; Cossor et al., 1999; Lyttle and Mason, 1997; Lyttle et al., 1999; Newble, 1982; Takahashi et al., 1983).

Among the arguments justifying the purpose of the applied set-up we must underline those crucial for the realization of the aims of the present study. Firstly, backstroke flags placed 5m away from the wall make it easier for the coach to assess the turn technique - (Blanksby et al., 1996a) – thus making the procedure applicable. Secondly, in the case of the monofin turn – for the sake of propulsive movement efficiency, the turn itself starts later, but the initiation of propulsive movement comes earlier in comparison to the freestyle turn. Thus, assessing the technique within a distance of 5m allows for concentrating analysis in the isolated turn action (Clothier et al., 2000a), during which the swimmer can lose relatively more time than during the propulsive movements connected with starting and finishing of the turn.

Realization of the purposes of the study, as well as the fact that no one has researched the monofin turn before, seems to justify the laboratory conditions of the experiments carried out. For it has been assumed that the conditions of turn performance during swimming competition differ considerably from those created during laboratory experiments (the precision of movement, attitude, motivation, emotions). In order to ensure the reliability and diligence of the analysis, the obtained results were related to works based on the same methodology. For the aforementioned reasons, it is hard to find grounds for comparing results obtained in laboratory conditions with those obtained during swimming competition. In spite of the standards established by studies dedicated to tradi-

tional swimming turn analysis, (Arellano, 1994, Haliand, 1988; 2006; Mason and Cossor, 2000; 2001) the experiences gained while carrying out the present research, along with considerable academic achievements of the authors quoted, will be used in future in research on the monofin turn in swimming competition conditions.

The low number of research subjects limits the diagnostics properties of the statistical instruments used to evaluate the technique of the monofin swimming turn. Many of the analyses of freestyle swimming are based on similarly scarce research material (the number of subjects is given in brackets) (Blanksby et al., 1995; 1996b; Clothier at al, 2000a; 2000b; Lyttle and Mason, 1997; Nicol and Kruger, 1979; Takahashi et al., 1983).

In taking advantage of the experiments of the authors mentioned, the resulting analysis has been limited only to descriptive statistics based on average values, Standard Deviation and only those parameters whose Standard Deviation values were lower than 35% of the corresponding arithmetic means. This seems to determine the quality of the results obtained in the statistical aspect. In order to validate the results in the cognitive aspect we need to make an assumption that the subjects, by virtue of their high technical level, performed the turns perfectly (which has been subjectively examined during the filmed analysis). In accordance with the aims of the paper formulated in the direction of facilitating the training process in both the didactic and applicational aspect, it may also be judged that from among the elite swimmers, due to automation of the movements, the differences in the turn technique are very slight. Therefore, it is assumed that the differences noted in a small group of subjects, may be generalized for a larger group representing the same level of technical mastery.

Achieving objectives, assumes the use of the analysis of turns performed by elite swimmers, for constructing a diagram containing the most crucial elements of the technique form the point of view of its coaching and improvement in the early stages of a career. The diagram is assumed to be a useful tool in evaluating a fin swimming turn that, when included into the specific technique, can provide training that prevents mistakes in inexperienced swimmers.

The results indicate (Figure 4), that contrary to common opinion, the measure of turn technique in monofin swimming is not in the striving for the fastest performance of all its components. The priority meaning for the quality of the turn technique is the optimum extension of duration of wall contact, the push-off time and glide time. In the context of interdependencies between the turn time and the total turn time ($r = -0.64$), the fact that extending the time-out reduces the total turn time ($r = -0.75$) explains the need for extending the activities performed from the moment of feet wall contact until finishing the glide in time. The negative correlation taking place between the total turn time and the time-in ($r = -0.75$) suggests the need for fast swimming in to the wall and performing rapid rotation.

The total turn time decreases together with reducing the time of swimming-in and reducing the time of commencement of stroking. The high correlations ($r > 0.9$) allow for a highly probable interpretation of the in-

terdependencies indicated. Similar results of research in the freestyle turn suggest that reducing the total turn time is conditioned by high swimming speed just before its initiation and just after finishing the glide (Blanksby et al., 1996a; Chow et al., 1984). While noting that the minimization of rotation time adds to reducing of the total turn time ($r = 0.65$), the formulated thesis may be extended by significant meaning of minimization of swimming-in time to the quality of monofin swimming turn. This belief is confirmed by the analyses of the freestyle turn, while it must be stated that the increase in the speed of swim-in results in initiating the turn further from the wall and with faster rotation (Chow et. al. 1984; Hay, 1986; 1992). Due to the necessity of maintaining the streamline position while reducing the drag during the turn, the swimmer should put his feet on the wall just after finishing the rotation (Nicol and Kruger, 1979). The specific character of monofin swimming forces a compromise on the finding of a possibly that the slightest flexion of legs, which allows for carrying them over the water so that; "extended" by the monofin "they would fit in the turn" is the most favourable position to start push-off.

Once reaching the wall, extending the duration of wall contact ($r = -0.92$) is the most crucial for reducing the total turn time. The role of this factor in the evaluation of the turn technique has been repeatedly emphasized (Blanksby et al., 1996a; Lyttle and Benjanuvatra, 2004). The swimmer, who devotes less time to wall contact, generates lower push-off force, not utilizing the energy generated by muscles. Takahashi et al. (1983), Blanksby et al. (1996a; 1996b) and Lyttle et al. (1999) mention the optimization of force used for push-off. It may be therefore assumed that optimally long wall contact time is required for the swimmer to prepare precisely for the push-off phase. From the practical point of view, the necessity of anticipating the force generated while preparing the push-off, is included in the statement that: at long distances, maximum energy should not be engaged in turns because it is needed to cover the distance. Blanksby et al. (1996a) have suggested that reducing knee joint flexion during the first wall contact reduces the total turn time in freestyle swimming. Similarly, more extended legs at the moment of wall contact shortens the distance to be covered by the swimmer after the turn, which leads to minimization of the total turn time (Blanksby et al, 1996b; Takahashi et al., 1983). With the assumption that optimization of leg extension, to a range allowing for generating propulsion, the results obtained (minimization of the total turn time with the monofin favours greater value of Tuck Index ($r = -0.75$) and smaller angle of knee joint flexion ($r = 0.60$), suggest the significance of the precise positioning of legs on the wall in order to prepare for an effective push-off. In the context presented, optimization of duration of wall contact in order to extend it, may be treated as a quality criterion in the monofin swimming turn technique.

Streamlining the process of teaching and perfecting the monofin turn by optimizing wall contact time requires awareness that, it is groundless to interfere with the turn technique of an elite swimmer, in order to deliberately delay the push-off time. The proposed suggestions are directed at less advanced swimmers; extending wall con-

tact time allows for more precise push-off preparation in order to avoid errors.

A significant correlation (r = -0.64) suggests extending the push-off phase time in order to minimize the total turn time. Analyses of the freestyle turn also attribute significant meaning to the push-off in the evaluation of the quality of technique (Lyttle et al. 1999; Walker, 1996). The correct push-off phase is indicated by: the appropriate combination of gradual minimization of drag, produced as a consequence of increasing the swimmer's velocity and extending push-off time for the optimal development of torque generating propulsion (Lyttle, and Mason, 1997; Lyttle, et al. 1999). Violent movements performed during the push-off significantly increase drag which results in unfavourable conditions for the body streamline (Clarys and Jiskoot, 1975). Therefore, push-off should be dynamic but gradual. The legs should be extended smoothly, so that the velocity increases uniformly until the moment when the feet lose contact with the wall. A too fast push-off (when the swimmer has not finished all movements related to body rotation before the impulse of their legs) reduces the time needed for developing optimal force impulse. Therefore reducing the potential possibility of utilizing the push-off energy (including the effect of elastic energy and muscle pre-stretch mechanism) (Lyttle et al., 1999). Additionally, it leads to generating maximum propulsive force while this phase is still taking place. As a consequence, the highest value of drag is created before the feet lose contact with the wall. Incorrect preparation for the push-off phase may also result in non-parallel positioning of the body to the swimming direction (Walker, 1996). The above mentioned arguments suggest that the optimal extension of push-off time may be treated as a quality criterion in monofin swimming turn technique. The precision of the push-off phase in the monofin turn seems to be more significant than in the case of freestyle swimming, due to the large surface of the monofin and the fact that both feet are immobilized in it. Both these factors hinder control of positioning the fin (feet) on the turn wall.

The positive value of the correlation coefficient with relation to the total turn time (r = 0.62), suggests striving for the minimization of the push-off distance. This interdependence may be interpreted as a consequence of limited flexion in the leg joints while initiating the push-off. This fact, along with rudimentary information on the diagnostic value of this parameter, suggests that it does not have an autonomic meaning in evaluating the quality of turns.

The diagnostic value of the push-off depth as a factor in evaluation of the monofin swimming turn technique is limited in the statistical sense (r = -0.51). It seems to be logical, however, that the glide depth is a consequence of, the positioning of leg segments while initiating push-off, taking into consideration that the angle of push-off was not really correlated to total turn time. As a consequence of moving water mass with a large monofin, at high velocity, over a short distance, with slight immersion in the swimmer, there are unfavourable hydrodynamic conditions on the water's surface caused by wave drag. Lyttle et al., (1998) claims, that the mentioned drag is 15 to 21% lower at a depth of 0.4- 0.6 m, than it is just under the

water's surface, suggesting in the freestyle turn, a push-off at the depth of approximately. 0.4 m. In this context one may advance a thesis that a deep push-off is justifiable, from the point of view of the quality, in the monofin swimming turn. Whereas the value of the parameter obtained in this study ($\overline{X}$ =0.47m) has a cognitive meaning, when it is treated as minimum depth of push-off.

The meaning of the push-off distance and the push-off depth is connected with validation of the average push-off velocity as a diagnostic factor in the evaluation of the monofin swimming turn. The obtained results indicate that the average velocity of the push-off as a consequence of "long" time, "short" distance and "deep" push-off, indicates significant correlation with the total turn time (r = 0.7). It seems that optimization of the velocity in order to minimize it may be treated as a criterion in monofin swimming turn technique. No direct confirmation of the thesis presented was found in freestyle turn analyses. It is also supported by suggestions, relating to the optimization of the push-off velocity, implying the avoidance of drag resulting from the accelerating body of the swimmer (Lyttle and Mason, 1997; Lyttle et al., 1998; 1999). Therefore, in the smoothly performed turn, generating the maximum push-off force is slightly delayed. This allows for a streamlined positioning of the swimmer's body and the initiating of the push-off in the horizontal direction (Lyttle et al., 1999; Lyttle and Benjanuvatra, 2004). The optimization of push-off velocity in order to reduce unfavourable hydrodynamic phenomena is also justified in the monofin turn. Due to the considerable velocity resulting from the use of the monofin to generate propulsion, it is not justifiable to produce additional drag resulting from haste in preparing and performing the push-off phase.

The glide phase is described by three parameters: glide time, glide distance and glide angle (Figure 4). The meaning of this phase in the evaluation of the turn technique is confirmed by the belief that the glide time constitutes approximately 10-20% of tine in swimming race, depending on the distance and swimming stroke (Chatard et al., 1990a). These results suggest that the quality of the monofin turn technique is indicated by the optimal extension of glide time (r = -0.6) and glide distance (r = -0.42), similar to the push-off phase. The analysis of the glide in the freestyle turn indicates that the glide time, distance and depth determine the horizontal velocity of the swimmer in this phase of the turn (Lyttle et al., 1998, 2000). It seems that the optimization of glide time in the direction of its extension is subordinated to minimization of drag appearing as a result of applying external forces generated during push-off - i.e. passive drag (Costill et al., 1992). The linear interdependence between the increase in passive drag and glide velocity clearly explains that the reduction of passive drag during the glide - transfers into a better total turn time (Lyttle et al., 1998). The minimization of the glide time (increase in velocity), disturbs the flow of water around the swimmer's body, increasing the component of drag friction, which as a function of laminar flow, should be minimal (Clarys, 1978a). In the economic use of push-off energy, attention to minimizing the body surface should help. This requirement may be easier to fulfil with reduced glide velocity (Clarys, 1978b;

Chatard et al., 1990b; Benjanuvatra et al., 2001; Lyttle et al., 1998). Because the wave drag decreases proportionally to the dimension of the length of the swimming body, the aspiration of maintaining the extended, tense and streamlined position as long as possible during the glide is justified, minimizing the body deviation in all directions (Larsen et al., 1981). Additionally, limiting the changes in glide velocity activates a positive influence on the additional water mass (Colman et al., 1999). From the point of view of training, it should be noticed, that a high level of body flexibility increases the potential possibilities of assuming streamline position during glide, creating better conditions for avoiding passive drag. (Chatard et al., 1990b). This study has indicated that monofin swimmers perform glides in a shorter time and in a shorter distance in comparison with crawl swimmers. The reason is the already mentioned much higher speed of monofin swimming. Therefore, the levelling of the glide velocity and the swimming velocity takes place much earlier in comparison with the freestyle turn, indicating the necessity of earlier commencement of stroking.

The interdependency between the glide angle and the total turn time ($r = 0.68$) comes very close to the statistical significance. It may be therefore concluded that the horizontal position of the swimmer's body during the glide will have significance on correct technique in a monofin swimming turn. A similar thesis, in relation to the freestyle turn, was stated by Costil et al. (1992). The significance of the glide angle on the mechanism of the effective turn may be evaluated only indirectly through the described interdependencies, connected with minimization of active drag after push-off. Optimization of glide depth results directly from the angle of body positioning towards the swimming direction and is marked by the possibilities of avoiding turbulence caused by the turn. On the other hand, the glide must be shallow enough for the swimmer to cover the shortest possible distance for surfacing within a distance of 15 m from the wall. When treating the monofin as part of the biokinematic chain of the swimmer's body, one may also refer to the results saying that the glide deeper than approximately. 0.2 of swimmer's body length significantly reduces the wave drag during the turn in freestyle (Larsen et al., 1981). In general the results of the study seem to confirm the thesis formulated in the case of push-off, that efficient and effective glide during the monofin swimming turn, must be performed deeper than in the freestyle turn. A range from 0.4 m to 0.6 m is assumed as the optimal glide depth in the freestyle turn (Hertel, 1966; Larsen et al., 1981; Lyttle et al., 1998).

There is a discussion under way among turn researchers over the optimization of position during the glide and commencement of stroking. Due to the specific character of monofin swimming there are some indications towards performing the glide and commencement of stroking in the lateral position. Subjective analysis of the filmed material confirms the opinion presented in reference to all subjects. The described relocation structure of the monifin swimmer during the turn phases examined is justified turough interpretation of the mechanism of propulsion generated by fish and marine mammals. The specific shape, the vertical dimension of body surface and the

oscillatory movements of the lateral surfaces make the water mass rotate, creating vortexes which are the source of propulsion in the horizontal direction (Triantafyllou and Triantafyllou, 1995; Ungerechts et al., 1999; Wu, 1971; Videler, 1993). Addaptations taken from nature dictate the delaying of rotation in the prone position after push-off and during commencement of stroking, in order to minimize the unfavourable phenomena created by the stern wave reverberating from the wall after push-off (Lyttle et al. 1999). This statement gains in significance in the case of the monofin swimming turn, where the stern wave is larger because it is created by the large surface of the monofin. In the freestyle turn, a 45º rotation during the glide gives better effect than the glide in a prone position with velocities bigger than 1.5- 1.6 m/s. (Clarys and Jiskoot, 1975) Being aware that the speeds obtained in monofin swimming are greater, the utility of the discussed property of the turn technique is confirmed.

Reduction of active drag, brought about by the swimmer's movements, is a criterion of the effectiveness of the commencement of stroking after the turn. Active drag is most of all, a consequence of changes in the shape of the body, resulting from relocation of its segments. Therefore it results mostly from the individual technique of the swimmer. In monofin swimming the nodal element of the propulsive movements are changes in the positioning of the segments of the legs at the knee joints. The effective movement of the fin resulting from the flexing of legs at the knee joints is the property of a technique characterising elite swimmers. Less experienced swimmers generate propulsion mainly as a result of leg extension (Rejman and Ochman, 2007). Assuming that the increase in drag caused by leg flexion decreases the swimming speed (Rejman et al., 2003), it may be concluded (on the basis of subjective observation of the swimmers tested) that the first movement after glide should be the extension of knee joints.

## Conclusion

Assuming that the quality of the monofin swimming turn technique is proven by the minimum time needed to perform it, basic criteria for turn evaluation should result from the analysis of the time structure of particular phases. Many from among the time criteria indicated, may be monitored with the use of a stop-watch, during training sessions, which gives them an applicational value in objectification of the technique evaluation. The main assumption, while formulating the aims of learning and perfecting turns at different technique levels, should be the conviction that an effective and efficient turn is not just a simple consequence of the fastest performance of all its component parts. The diagram describing the factors contributing to turn technique was created on the basis of a deterministic system of dependencies, and specifies the following most important criteria for the quality of the monofin swimming turn: striving for extension - in the optimal range- of wall contact time, the time of the push-off phase and the glide time. Optimization of wall contact time is determined by the time necessary for precise preparation for push-off. Preparation for push-off is proven by setting leg segments within the scope of exten-

sion, which guarantees the most effective use of the torque generated by the muscles. The optimization of push-off time and glide time is subordinated to the maximum use of the potential generated while extending legs, with simultaneous minimization of active drag. It is then inevitable to reduce the glide velocity which may be obtained by extending the glide distance and increasing immersion. During the glide phase a swimmer should swim in a horizontal, lateral position. Such a body position should be also maintained during commencement of stroking. Due to the effectiveness of the propulsion, the first movement after finishing the glide, should be the extension of the knee joints.

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## Key points

- Short time and large surface of the monofin additionally hinders complexity of the turn performance by disturbance in sensing and controlling body in water. Availability of no objective data on monofin swimming turns resulted in research in the field connected with specifying parameters needed for the technique evaluation.
- Correct turn technique may help to improve swimming race results.
- The diagram constructed on the basis of the interdependency of the total turn time and the remaining recorded kinematic parameters should establish the areas of searching for mechanism of effective and efficient monofin swimming turn.
- The most crucial, from the coaching and improving point of view, seem to be activities which take place from the moment of feet wall contact till the first propulsive movements. Therefore, the high quality of the monofin swimming turn technique is not just a simple consequence of the fastest performance of all its component parts.
- The most important criteria of the quality in the monofin swimming turn technique are: striving for extending in the optimum scope of wall contact time, the time of the push-off phase and the glide time.

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