

# Assessing the impact of a targeted plyometric training on changes in selected kinematic parameters of the swimming start

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*Purpose:* The aim of this study was to analyse changes taking place within selected kinematic parameters of the swimming start, after completing a six-week plyometric training, assuming that the take-off power training improves its effectiveness. *Methods:* The experiment included nine male swimmers. In the pre-test the swimmers performed three starts focusing on the best performance. Next, a plyometric training programme, adapted from sprint running, was introduced in order to increase a power of the lower extremities. The programme entailed 75 minute sessions conducted twice a week. Afterwards, a post-test was performed, analogous to the pre-test. Spatio-temporal structure data of the swimming start were gathered from video recordings of the swimmer above and under water. *Results:* Impulses triggered by the plyometric training contributed to a shorter start time (the main measure of start effectiveness) and glide time as well as increasing average take-off, flight and glide velocities including take-off, entry and glide instantaneous velocities. The glide angle decreased. *Conclusions:* The changes in selected parameters of the swimming start and its confirmed diagnostic values, showed the areas to be susceptible to plyometric training and suggested that applied plyometric training programme aimed at increasing take-off power enhances the effectiveness of the swimming start.

*Key words:* swimming start, plyometry, effectiveness

## 1. Introduction

The swimming start is an integral part of all swimming events. The quality of this technical component of swimming influences the results obtained in inverse proportion to the length of distance covered. Starting time (the sum of the number of temporal units of the several phases of swimming start, between response to a start signal to the beginning of stroking – appropriate to the swimming event [6]), represents approximately 0.8% of the time obtained during the race over a distance of 1500 metres freestyle, and approximately 26.1% of sprint event (50 metre freestyle) [3]. Therefore, studying the performance of the swimming start is important for both scientists and coaches.



Fig. 1. Track-Start: starting position

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The performance of the swimming start has been discussed mostly in two variations a track start (feet staggered (Fig. 1)) and a grab start (feet parallel to the edge of starting block). The track start compared to the grab start is characterised by a longer time elapsing from the start signal until the swimmer's centre of mass (CM) shifts forward as well as smaller angle of entry into the water [9]. Nonetheless, it seems that swimmers' preferences for track start include: a greater total take-off power, a reduction in track-starting time, and in a more stable position on the starting block (avoiding a false start) [16]. Considering these differences and swimmers' preferences and almost universal use of the track start during competitions, this technique was examined in this research.

The effectiveness is defined as an action leading to a targeted goal [11]. In line with other studies, the effectiveness of the swimming start is understood as performing a start in the shortest possible time [6], [7]. Therefore, minimising of starting time was assumed as a key criterion for its performance. Additionally, minimising the take-off phase time would also result in shorter starting time [9]. Meanwhile, the process of generating maximum torque necessary for effective take-off requires time to put the leg muscles in a standby mode (extension-contraction) [23]. Performance of the swimming start is also determined by the take-off angle [9]. The take-off at the wrong angle requires correction of flight trajectory, which leads to increased flight time, decreased velocity, and errors during entry into the water. When the angle of the take-off is smaller, the angle of water entry is also smaller resulting in higher velocity during the flight phase, entry into the water and the glide phase [9]. The take-off that directs the flight (flat or parabolic) influences the duration of the swimming start. The longer distance covered in the above water phase of the start and the shorter their of flight time mean that the swimmer covers the distance to the entry point in a shorter time. This is because flight velocity is much higher than the velocity obtained during swimming. When entering the water, the body of a swimmer should submerge in the same point as the first contact of their fingers with the surface. This minimises the resistance resulting from transition of the body to an environment with much higher density [16]. In order for swimming start to be effective, the velocity of the flight phase should differ as little as possible from the velocity obtained in the glide phase while the swimmer should maintain a streamlined underwater position until glide velocity decreases to a value capable of being maintained during the swim [3]. These criteria for the effectiveness of the swimming start were

a background for selection of the kinematic parameters for the analysis.

Complete information about kinematic and dynamic structure of movement is a necessary condition for objective, biomechanical analysis. The dynamic structure of movement contains information about forces that induce the movement and forces resulting from the reaction of the environment. The kinematic structure describes the effects of these forces which enables determination of functions and mechanisms of interaction between different segments of the body [8]. The technical training methods aimed at increasing the effect of performance of the swimming start interfere with external (kinematic) forms of movement, but rarely affect its dynamics. Therefore, an attempt was made to demonstrate that training focusing on the power of lower extremities may improve the effectiveness of the swimming start.

The power is understood as the muscles' ability to perform the greatest possible work in the shortest period of time [19]. During the start, the increase in the force results in a reduction of contact time with the starting block, as well as shortening the time of the flight phase (relative to its length). Assuming that flight velocity always exceeds swimming velocity, the take-off power becomes important for the effectiveness (shortening of the time) of the swimming start [23]. Therefore, the swimming start can be perceived as an explosive pattern of movement [18], while the power as a motor ability can respond to training stimuli [1]. Previous studies in track and field [23], basketball [17], cycling [2], and ice hockey [13] have indicated that plyometric training is conducive for developing power of the lower extremities. However, no impact of this type of training on the power of the take-off during the swimming start has been confirmed so far [1], [4], [5]. Thus, there is a need for scientific verification of the suitability of plyometric training exercises for improving the swimming start.

Generally, plyometric training uses two factors involved in the functioning of skeletal muscles: 1) relationship between force (strength) and length of the muscle – a muscle that is extended beyond its resting length generates more strength due to a rise in tension levels on the passive connective tissue components of the movement; 2) relationship between force (strength) and velocity of the muscle contraction – a muscle generates the largest strength with a negative velocity of contraction, that is, during the eccentric contraction. Therefore, the more abruptly the movement stops when the muscle is extended the greater is the value of force generated. The shorter the time between eccentric and concentric contraction the greater the force

released by the muscle [21]. The force generated by muscles is limited by their physiological elasticity dependent on muscle tissue resistance. Therefore, plyometric training should be based on rational programming.

This research is focused on the technique of track-start in swimming, before and after plyometric training. The swimming start technique was tested in terms of its effectiveness – performing a start in the shortest possible time. The study was conducted to analyse changes taking place within selected kinematic parameters of the swimming start after completing a six-week plyometric training. The implementation of plyometric training programme was hypothesised to improve the effectiveness of the swimming start technique. The hypothesis was verified performing the following research tasks:

1. Identifying parameters describing the swimming start technique that undergoes changes resulting from plyometric training stimuli.
2. Identifying the directions of changes in the kinematic parameters of the swimming start that determine its effectiveness in order to indicate areas of possible and beneficial impacts of plyometric training.
3. Demonstration of the reproducibility of changes in the spatio-temporal structure of the swimming start, most likely influenced by plyometric training, in the group of swimmer, in order to verify diagnostic value of the results obtained.

The practical application of this study is expressed by an interpretation of findings on improvements in the swimming start technique made for educational purposes.

## 2. Methods

### *Participants*

Nine male, national level swimmers of similar ages ( $21.89 \pm 3.41$  years) and body compositions ( $179.4 \pm 0.10$  cm;  $75.11 \pm 6.60$  kg), with a minimum of five years' experience in training and competing ( $7.97 \pm 3.02$  years) volunteered for this experiment. The standard deviation of BMI measures which did not exceed 10% of the arithmetic mean for all subjects [20]: 2.47 BMI ( $\pm 0.78$ ), the homogeneity of the examined group. Based on the experience of the previous researches (with experimental and control groups [1], [4], [5]) and due to the fact that all the swimmers used track start as their preferred method of starting, they were allocated to one group. No

control group was created. None of the swimmers reported health problems or injuries before the programme. Before the start of the plyometric training programme the swimmers were informed about the purpose and methods of the experiment and agreed to participate. Consent from was obtained from the participants prior to any plyometric training and testing. The research protocol consistent with the Helsinki declaration was approved by the University's Ethics Committee.

### *Experimental procedure*

The experiment lasted eight weeks. During this time the swimmers conducted the training in water as part of a preparatory period (average volume of load per week was  $50 \pm 4.68$  km). A test (pre-test) was performed evaluating the effectiveness of the start, where after a warm-up each swimmer performed three starts from a starting block (on digital signal – (Colorado Time System, USA)) All of them used the track start as the technique mostly preferred by high level swimmers. Subjects were instructed to concentrate on the possibly best performance in each trial and not perform any propulsion movements after the start, maintaining a glide [6], [7]. The positioning of feet in the starting position was not specified, however all swimmers put their left foot on the edge of the platform. Five-minute breaks between trials eliminated the effect of fatigue.

### *Plyometric training*

During the following week, a plyometric exercise programme was introduced, focusing on developing explosive power of the lower and upper extremities in the swimming start (experimental factor). In order to implement the programme, plyometric exercises were used, borrowed from track and field running trainings [10], [14], [19]. The fact that swimmers were not previously subjected to the plyometric training stimuli was taken into account during creating of structure of the training programme and choosing the amount of load (Table 1). The plyometric intervention programme consisted of various skips, bounds, hops, and jumps in vertical, horizontal and mixed directions targeted at lower extremities as well as special exercises with a dumbbell and medicine ball for upper extremities. During the plyometric intervention programme, a progressive overload of stimuli was applied by varying the complexity of movements and increasing the load (number of foot contacts and ball passes). The intensity of stimuli reached a maximum in the last two training sessions. Periodised

Table 1. Summary of the training programme including special dynamic strength exercises

Weeks	Workout 1	Sets	Reps	Load	Workout 2
	Exercise				Exercise
1/3	Power skipping (skip A)	2	–	10 m	Power skipping (skip A)
	Squat jump	2	10	–	Jumping alternating step-ups (40cm box)
	Push-ups	2	10	–/10 kg	Jumping jacks (plates)
	Chest passes (medicine ball)	2	10	3 kg	Chest passes (medicine ball)
	Power skipping (skip C)	2	–	10 m	Power skipping (skip D)
	Knee-tuck jumps	2	10	–	Alternate jumping high knee
	Over-head throw (medicine ball)	2	10	3 kg	Over-head throw (medicine ball)
	Lifting the weights over-head (plate)	2	10	10 kg	Lifting the weights over-head (plate)
Alternate sprint bounding	3	–	30 m	Double speed hops	
2/4	Power skipping (skip A)	3	–	10 m	Power skipping (skip A)
	Squat jump	3	10	–	Jumping alternating step-ups (40 cm box)
	Push-ups	3	10	–/10 kg	Jumping jacks (plates)
	Chest passes (medicine ball)	3	10	3 kg	Chest passes (medicine ball)
	Power skipping (skip C)	3	–	10 m	Power skipping (skip D)
	Knee-tuck jumps	3	10	–	Alternate jumping high knee
	Over-head throw (medicine ball)	3	10	3 kg	Over-head throw (medicine ball)
	Lifting the weights over-head (plate)	3	10	10 kg	Lifting the weights over-head (plate)
Alternate sprint bounding	3	–	30 m	Double speed hops	
5	Power skipping (skip A)	4	–	10 m	Power skipping (skip A)
	Squat jump	4	10	–	Jumping alternating step-ups (40 cm box)
	Push-ups	3	10	–/10 kg	Jumping jacks (plates)
	Chest passes (medicine ball)	3	10	3 kg	Chest passes (medicine ball)
	Power skipping (skip C)	4	–	10 m	Power skipping (skip D)
	Knee-tuck jumps	4	10	–	Alternate jumping high knee
	Over-head throw (medicine ball)	3	10	3 kg	Over-head throw (medicine ball)
	Lifting the weights over-head (plate)	3	10	10 kg	Lifting the weights over-head (plate)
Alternate sprint bounding	4	–	30 m	Double speed hops	
6	Power skipping (skip A)	5	–	10 m	Power skipping (skip A)
	Squat jump	5	10	–	Jumping alternating step-ups (40 cm box)
	Push-ups	3	10	–/10 kg	Jumping jacks (plates)
	Chest passes (medicine ball)	3	10	3 kg	Chest passes (medicine ball)
	Power skipping (skip C)	5	–	10 m	Power skipping (skip D)
	Knee-tuck jumps	5	10	–	Alternate jumping high knee
	Over-head throw (medicine ball)	3	10	3 kg	Over-head throw (medicine ball)
	Lifting the weights over-head (plate)	3	10	10 kg	Lifting the weights over-head (plate)
Alternate sprint bounding	5	–	30 m	Double speed hops	

training avoided injuries and allowed to adapt to neural stress. Each training session lasted approximately 75 minutes and included 15 minutes of specific warm-ups including short jogging, stretching, light jumping and skipping exercises. The plyometric exercises were divided into two independent workouts, each performed on a different day – Monday and Thursday (Table 1). The subjects performed all exercises in a dynamic manner (focusing

on achieving maximal height or length of the swimming start or maximal force of ball thrusts). Each training session was conducted by only one professional plyometric training coach. After completing the plyometric training programme another test for the swimming start was carried out (post-test). The test was based on performing an analogous research task, just like the one during the pre-test.

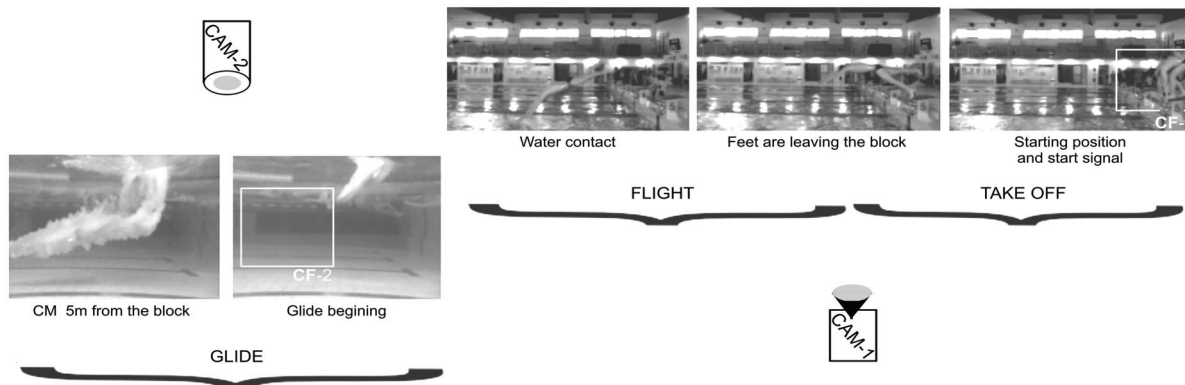


Fig. 2. Explanation of experimental setup and illustration of phase-division of the swimming start.

The take-off phase was defined as the phase from the starting signal until the last contact of feet with a starting block; flight phase – from the last contact of feet with the block until the first contact of swimmer's body (hands) with the water's surface; glide phase – from the first contact of swimmer with the water until the swimmer (CM) passed a distance of 5 metres from the edge of the starting block (according to Hay, 1986 [7]). *Note:* CAM-1, CAM-2 – Camera; CF-1, CF-2 Calibration frames

### Data acquisition

Data for analysis were collected on the basis of film material recorded during a pre-test and post-test. A camera (Panasonic HC-V210, Japan (Figure 2 (K-1))) was placed above the water to register the swimmer's movement during take-off and flight phases – until entry into the water. An identical second camera (Fig. 2 (K-2)) was placed under the water at a depth of 1 metre, just 5 metres from the edge of the starting block. It recorded the swimmer's movement upon entry into the water and in the glide phase. The cameras were positioned so that their lens axes were set perpendicular to the recorded subject. The image was cropped so that you could see the largest possible view of the tested subject. The frequency of filming was 100 Hz. Time synchronisation of images recorded by the cameras was guaranteed by timestamp (light flashing at a frequency of 100 Hz, visible both under and above the water surface). The real dimensions of the recorded image were determined by means of calibration, which consisted of calibration frames (2 m × 2 m), placed above and under water surface. Both frames were set in a transverse plane, perpendicularly to the swimmers' bodies and to the cameras (Figure 2 U-1 and U-2). There was also a marker under water marking a distance of 5 metres from the starting block. Light markers were used to identify the displacement of the swimmer's body. It was assumed that the CM of the human body is located near the navel. This is where the marker was placed, on the side of the trunk, in line with the body's longitudinal axis [19]. The second marker was placed on the axis of the shoulder joint. Trials were carried out in the same conditions in an indoor swimming pool.

In order to quantify the parameters of spatio-temporal structure of the swimming start recorded during tests, SIMI Movement 2D software (SIMI Reality Movement Systems 2D, GmbH, Germany) was used. Digital processing of the recorded footage showed analogue recording of the selected parameters of swimming start in a time function.

In this study the phase-division of the swimming start was adapted from the Hay's deterministic model [7] (Fig. 2). According to this pattern in both experimental trials the following swimming start parameters (independent variables) were determined.

1. Temporal structure parameters
  - a) Start time – time from the final shifting of CM point forward, before reaching a distance of 5 metres [6, 7] from the edge of the starting block.
  - b) Take-off time – time from the final shifting of CM point forward, until the last contact of feet with the starting block.
  - c) Flight time – time from the last contact of feet with the starting block, until first contact of swimmer with the water surface, determined by CM point.
  - d) Glide time – time from the first contact with the water's surface, before reaching a distance of 5 metres.
2. The spatial structure parameters
  - a) Take-off angle – angle defined by the line drafted between points marked on the shoulder joint axis and on the point adopted as CM, with a horizontal line crossing through it, at the time of last contact of feet with the starting block.
  - b) Entry angle – angle defined by the line drafted between points marked on the shoulder joint

- axis and on the point adopted as CM, with a horizontal line crossing through it, at the time of first contact with the water.
- c) Glide angle – angle defined by the line drafted between points marked on the shoulder joint axis and on the point adopted as CM, with a horizontal line crossing through it, at the time of CM reaching a distance of 5 metres from the edge of the starting block.
  - d) Depth of swimmer submersion in the glide-phase – the distance from the water's surface defined by the point adopted as CM and the water level line (the lower edge of the pool rope) at the time when CM was exactly 5 metres from the edge of the starting block.
3. Average velocities
    - a) Take-off average velocity – velocity from the final shifting of CM point forward, until last contact of feet with the starting block.
    - b) Flight average velocity – velocity of CM from the last contact of feet with the starting block, until first contact with the water's surface.
    - c) Glide average velocity – velocity of CM from the first contact with the water's surface, before reaching a distance of 5 metres from the edge of the starting block.
  4. Instantaneous velocities
    - a) Take-off instantaneous velocity – velocity of CM at the last contact of feet with the starting block.
    - b) Entry instantaneous velocity – velocity of CM at the first contact with the water's surface.
    - c) Glide instantaneous velocity – velocity of CM before reaching a distance of 5 metres from the edge of the starting block.
  5. Differences between instantaneous velocities
    - a) Difference between take-off instantaneous velocity and entry instantaneous velocity.
    - b) Difference between entry instantaneous velocity and glide instantaneous velocity.

#### Statistics

Statistical analysis was conducted using Statistica 10.0 software (StatSoft, USA). The homogeneity of the group allowed for a comparison of results illustrating changes which, most likely, occurred due to the plyometric training, within adopted parameters, as means of assessing the effectiveness of the swimming start.

An analysis was performed of the arithmetic means derived from the parameter values determined for each of the three trials (in both pre and post-tests). The measure of variability of the parameter value in

three swimming starts was equal to a standard deviation of less than 10% of the average value of this parameter [20]. This assumption was based on Bartlett's test for verifying the hypothesis of homogeneity of variance in all subgroups in a given population [20]. The test, based on statistics that have an asymptotic  $X^2$  distribution, can be used for small samples. The test verified that the relationship between means and standard deviations from the trial reflected the homogeneity of results obtained by the examined swimmers.

By using non-parametric Student's *t*-test for independent samples, statistical differences between initial measurements (trials during pre-test) and final measurements (trials during post-test) were determined, for all parameters assessing the effectiveness of the swimming start (dependent variables). The data satisfied the prerequisites for using the test (normality of distribution of variables and homogeneity of variance).

In order to identify relationships within variables that exhibited a statistically significant difference in relatively small group ( $n = 9$ ), Pearson's correlation coefficients between parameters in the pre-test and post-test were calculated. All statistical tests were carried out at a significance level  $\alpha = 0.05$ .

### 3. Results

In the first part of the analysis, statistical differences between mean values (in each of the three trials) of the swimming start parameters obtained during the pre-test and post-test were estimated using Student's *t*-test.

The results implied (Table 2) that the use of plyometric training changed the following spatio-temporal parameters of the swimming start: start time, glide time, take-off average velocity, flight average velocity, glide average velocity, take-off instantaneous velocity, entry instantaneous velocity, glide instantaneous velocity, and glide angle.

The direction of changes in the kinematic parameters of the swimming start was based on the differences between the values, recorded or estimated during the pre-test and post-test (Table 3). The results indicated that after plyometric training the start time and the glide time were reduced and the average take-off, flight and glide velocities were increased, as well as take-off, entry and glide instantaneous velocities; the glide angle was decreased.

In order to identify the areas of postulated impact of plyometric training, an attempt was made to

Table 2. Statistical differences (evaluated by Student’s *t*-test) between the values of swimming start parameters, obtained during the pre-test and post-test

Parameters		<i>t</i>	<i>df</i>	<i>p</i>	Confidence +95,000%
Temporal structure	Start time	4.6652	26	0.000081*	0.20169
	Take-off time	-0.2459	26	0.807676	0.02725
	Flight time	-1.5043	26	0.144568	0.00516
	Glide time	6.6059	26	0.000001*	0.20687
Spatial structure	Take-off angle	-1.0301	26	0.312470	2.0685
	Entry angle	1.2396	26	0.226197	4.9128
	Glide angle	3.4617	26	0.001869*	10.8449
	Depth of swimmer submersion in glide-phase	0.5962	26	0.556215	0.0939
Average and instantaneous velocities	Take-off average velocity	-2.6645	26	0.013068*	-0.05907
	Flight average velocity	-4.8177	26	0.000054*	-0.40687
	Glide average velocity	-6.3270	26	0.000001*	-0.48969
	Take-off instantaneous velocity	-4.5000	26	0.000126*	-0.35933
	Entry instantaneous velocity	-4.6404	26	0.000087*	-0.41881
	Glide instantaneous velocity	-5.4271	26	0.000011*	-0.30862
Differences between instantaneous velocities	Entry – End of take-off	-0.90267	26	0.374989	0.11542
	End of glide – Entry	-1.23285	26	0.228665	0.17021

\*statistical significance level ( $p \leq 0.5$ ).

Table 3. Changes within the statistically significant parameters of the swimming start following a six-week plyometric training

Parameters		Pre-test	Post-test	Difference Module %		
Temporal structure	Start time [s]	1.87	1.73	0.14	7.49	Shorter
Spatial structure	Glide time [s]	0.94	0.78	0.16	17.02	Lower
	Glide angle [deg]	14.94	8.14	6.8	45.52	
Average and instantaneous velocities	Take-off average velocity [m/s]	1.88	2.14	0.26	13.83	Higher
	Flight average velocity [m/s]	3.77	4.48	0.71	18.83	
	Glide average velocity [m/s]	2.49	3.21	0.72	28.92	
	Take-off instantaneous velocity [m/s]	3.38	4.04	0.66	19.53	
	Entry instantaneous velocity [m/s]	4.34	5.10	0.76	17.51	
	Glide instantaneous velocity [m/s]	1.93	2.42	0.49	25.39	

identify parameters affecting the minimisation of start time. Based on the values of the correlation coefficients (Fig. 3), significant, inversely proportional relationships were found between the start time and glide time (pre-test  $r = -0.80$ ; post-test  $r = -0.93$ ), average velocity (pre-test  $r = -0.66$ ; post-test  $r = -0.67$ ) and the instantaneous glide velocity (pre-test  $r = -0.66$ ; post-test  $r = -0.78$ ). The correlation coefficients values calculated after completing the plyometric training were greater than before training. It is worth emphasising that after the training, the shortening of start time was accompanied by an increase in

the average velocity of take-off (pre-test  $r = -0.28$ ; post-test  $r = -0.72$ ).

In order to investigate the reproducibility of changes in the spatio-temporal structure of the swimming start that occurred in the group of swimmers as a result of plyometric training, the results obtained during the pre-test and post-test (parameters verified statistically (Table 2)) were ranked according to minimisation of the start time ranking. The order of examined swimmers was the same in both trials, allowing for Pearson’s correlation coefficients between values of juxtaposed pairs of parameters to be calculated (Table 4).

Table 4. Values of Pearson's correlation coefficients ( $n = 9$ ) between the statistically significant parameters during the pre-test and the post-test (for all overall data according to the minimisation of start time ranking)

	Temporal structure		Spatial structure	Average and instantaneous velocities					
	Start time	Glide time	Glide angle	Take-off average velocity	Flight average velocity	Glide average velocity	Take-off instantaneous velocity	Flight instantaneous velocity	Glide instantaneous velocity
Pre – test →									
	0.76*	0.85*	0.57	0.25	0.13	0.78*	0.01	0.45	0.76*
Post – test →									

\* statistical significance level ( $p \leq 0.5$ ).

The reproducibility of changes in the spatio-temporal structure of the swimming start that took place as a result of plyometric training was shown in the form of significant, directly proportional correlations between the values of: start time (the main measure of effectiveness) and the parameters describing changes within the glide phase (glide phase time, average velocities and instantaneous velocities registered 5 metres from the starting block) (Table 4).

## 4. Discussion

The aim of this study was to analyse changes taking place within selected kinematic parameters of the swimming start, following completion of a six-week plyometric training, assuming that a training based on this methodology, aimed at increasing the take-off power, will improve the performance of the swimming start.

Analyses were based on an established, phasic breakdown of the swimming start, using standard parameters of spatio-temporal structure of swimming start technique [8]. Having knowledge of the more precise methods of analytical description and of scientific validations of other swimming start parameters [6], [16], [23], it appeared that the selected parameters were a reliable and objective source of knowledge used in quantitative and qualitative assessment of the effectiveness of swimming start technique [7]. In line with this statement confirmed by the methodology employed in aforementioned studies, the assessment of reaction time to the starting signal as a skill determined by individual neuromuscular (not biomechanical) capacities, were not taken under consideration in this research.

As mentioned before, the start time and time parameters of its various phases (with emphasis on the significance of glide phase) were regarded as indicators of effectiveness of the swimming start. Test results indicated that after plyometric training the start time was reduced by 0.14 s compared to the time before the training. For glide time the difference was 0.16 s (Table 3). Similar results were obtained by Davies et al. [5], following a six-week plyometric training, where shorter start time (by 0.07 s) and shorter time of glide phase (by 0.09 s) were observed. It seems that in the examined group of swimmers the start time and the glide time underwent desirable changes due to the plyometric training stimuli. Moreover, as the statistical relationships (Table 3 and Figure 4) confirm, minimisation of start time improves the effectiveness of the swimming start. At the same time, a shortening of the time of glide phase seems to be important for its effectiveness[1], [4].

Comparing the pre-test and post-test results (Table 3), a decrease in the value of glide angle was observed (about 6.8 degrees.) This result corresponded with the values obtained by Maglischo [16]. Supporting this author, a low value of glide angle (typical in sprint starts), results in higher velocity during this phase of the start. Therefore, this parameter can be considered as an important factor influencing on improvement of the effectiveness of the swimming start. One can also assume (despite the lack of statistical significance) that minimisation of the glide angle as a consequence of high velocity of the swimmer in this phase of the start, may have occurred as a result of plyometric training [9]. The instantaneous velocities determined in the post-test during the take-off phase (4.04 m/s) and during entry into water (5.10 m/s) (Table 3) corresponded with the results of Lee et al. [12] (4.35 and 5.31 m/s, respectively). The instantaneous velocities of take-off and glide published by Welcher et al. [25] also differed slightly from the re-



sults obtained here (by 0.14 m/s and 0.26 m/s, respectively). After plyometric training an increase in the average velocity of the take-off phase (about 0.26 m/s) and in the instantaneous velocity at the end of this phase (about 0.66 m/s) was also noted (Table 3). The average velocity of flight phase increased by 0.71 m/s while the instantaneous velocity of entry into the water increased by 0.76 m/s. An increase was observed in the average velocity of glide phase (by 0.72 m/s) and

upon its completion (by 0.49 m/s). These results suggest that the changes in parameters describing the velocity of the swimmer in subsequent phases of the swimming start may have occurred as a result of targeted plyometric training. Also the relationships between start time (criterion of effectiveness) and the average velocity of glide and instantaneous velocity at the end of the glide (Fig. 3) suggest that intensification of velocity in the glide phase may constitute indi-

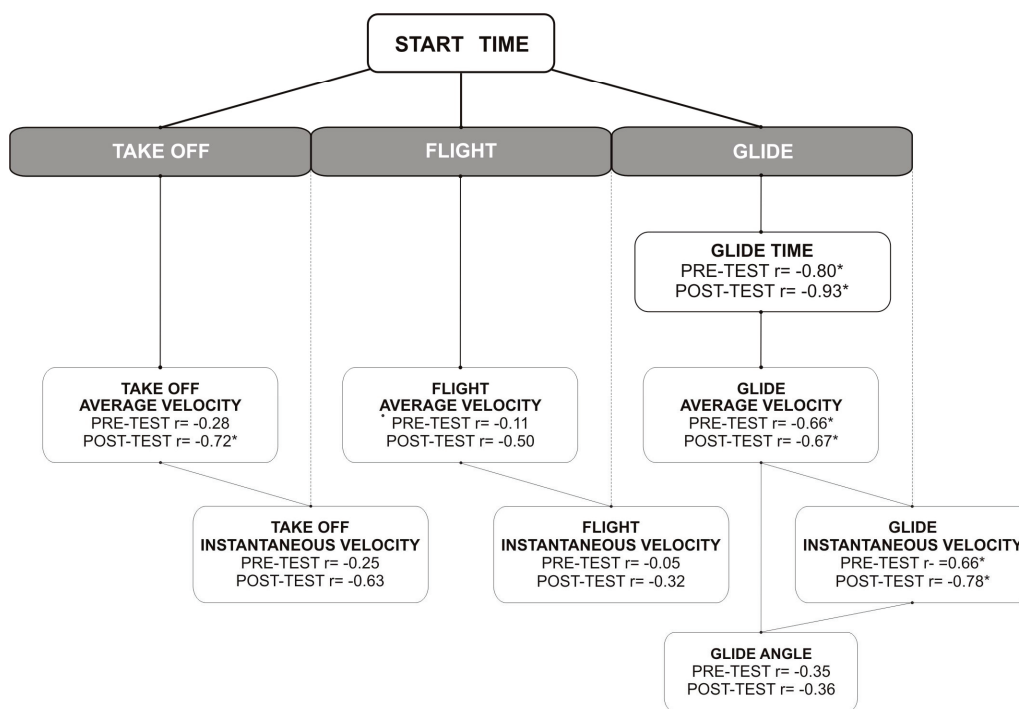


Fig. 3. Illustration of Pearson’s correlation coefficients ( $n = 9$ ) for start time and parameters of spatio-temporal structure that changed after the training (results obtained for all swimmers during pre-test and post-test, were examined in correlation analyses (according to Guimaraes and Hay, 1985 [6])

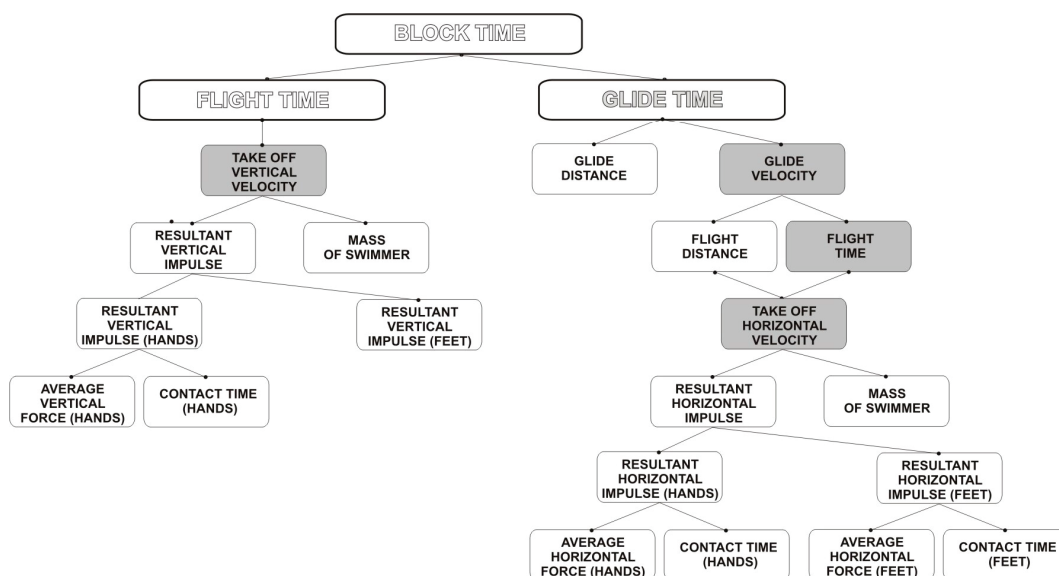


Fig. 4. Location of parameters in a model configuration of factors determining the efficiency of the swimming start (according to Guimaraes and Hay, 1985 [6])

rect indicator of effectiveness of the swimming start. It must be taken into consideration that the diagnostic value of glide velocity should be assessed by the prism of high dependence between the glide time (“breakout time”), and swimmer’s body shape, orientation and depth of entry [5]–[7], [22], [25]. The fact that average velocities of take-off significantly correlated with the values of start time only in the post-test results highlights how this parameter responds to plyometric training.

In the examined group of swimmers, the reproducibility of results in the case of start time and parameters describing performance in the glide phase confirmed the changes taking place in the spatio-temporal structure of the swimming start possibly are the result of plyometric training. At the same time, it positively verifies previously suggested diagnostic value of: the start time, glide phase time and average velocities as well as instantaneous velocities registered 5 metres from the starting block [6], [7]. This form of auto-validation of the results confirms in logical meaning the pertinence of the research procedures employed in this study. In this context, the above-mentioned comparison of the results of current study, with the results obtained with two – experimental and control – groups [1], [4], [5] seems to justify that the control group (no plyometric training) employed into the research would not change the sound of the results obtained in this study.

At this stage of the discussion, one may be inclined to conclude that in the examined group targeted plyometric training could be responsible for improving the technique of the swimming start. Its theoretical justification can be based on the interpretation of a model of configuration of factors determining the performance of swimming start [6] (Fig. 4).

A relationship between take-off power and velocity of the swimmer in subsequent phases of the swimming start appears to be critical for the aforementioned reasoning (Formula 1).

$$\frac{dW}{dt} = \left( \frac{Fs}{t} \right) = \text{POWER} = Fdv, \quad (1)$$

where:  $dW$  = work,  $dt$  = work time,  $F$  = force,  $dv$  = velocity resulting from action.

Interpretation of the left side of *formula 1* reveals that intensification of the take-off power can have an effect that the swimming start will be performed: faster with the same force or with greater force and the same time, or faster and with greater force at the same time. It is true that the time of the take-off phase has not changed in a statistical sense after introducing

plyometric training so following Vantorre et al. [23] it can be confirmed that minimising the take-off time does not determine the effectiveness of the swimming start. To generate maximum power of the lower extremities the time necessary for their extension (from the moment of taking on the starting position right until the beginning of straightening the legs) and effective contraction is critical. Thus, it is likely that plyometric training caused an increase in the functional capacity of leg muscles to generate maximum torque in the examined group of swimmers. Consequently, the take-off time did not change relative to the increase of take-off power, while the potential strength (force) accumulated in the muscles was utilized in the form of high velocity at the end of the take-off phase in majority of the swimmers examined [7]. However, the lack of signs of reproducibility in the results illustrating changes in the average velocity of take-off after plyometric training (Table 4) classifies the swimming start’s effective take-off as a dynamic – explosive act. The right side of *formula 1* shows factors that affect the power developed by the muscles of the extremities (a product of force ( $F$ ) and velocity of muscle contraction ( $dv$ )) confirming the desirability of explosive training (plyometric) with a small load which affects the speed of muscle contraction in motor activities where (as in the swimming start) little resistance is overcome.

The impulse-momentum relationship for both the vertical and horizontal directions in particular phases of the swimming start can be described [6] by the following principles of the conservation of momentum (Fig. 2, Formula (2))

$$\Delta p = \int_{t_1}^{t_2} F(t) dt, \quad (2)$$

where: impulse is an integral part of force ( $F(t)$ ), over time interval ( $dt$ ), on which it acts, and torque ( $p$ ) one the products of mass ( $m$ ) and velocity ( $v$ ) of the swimmer’s body. Assuming that the mass of the swimmer is constant ( $m$ ), it can be said that the force generated on the block by the swimmer is equal to his or her mass and acceleration ( $a$ ) (Formula (3))

$$F = m \frac{dv}{dt} = ma. \quad (3)$$

Therefore, the potentially higher ability to generate take-off power as a result of plyometric training can be transferred to an increase of velocities in flight and glide phases. The increase in the values of instantaneous velocities in the group of swimmers, following the training could also be interpreted as a consequence of



Fig. 5. Illustration of shared characteristics in the movement structure of the swimming start (Track-start) and track and field start (Block-start)

the increase in explosive power, achieved as a result of plyometric training [23].

The programme of targeted plyometric training created for the swimming start was adapted from training for sprint running [10], [14], [15]. This follows from the assumption that their kinematic and dynamic structures are similar to the swimming start. In track and field and swimming start, the starting position and the take-off are two phases only which can be taken into comparison. Similarities between both of the starts were illustrated in Fig. 5. A specialised, targeted nature of plyometric exercises used in training for the swimming start was achieved by modifying the block start forms (track and field). The elementary structure of movement was not interfered with, only the starting positions of exercises (feet staggered as in the swimming start) were modified. Further, a more horizontal direction of take-off was enforced, in comparison to the block start. In light of the results obtained, the idea of adapting the methodology of the block start (from track and field) plyometric training to the swimming start technical training appears to be justified.

Thus, the changes in selected spatio-temporal structure parameters of the swimming start, shown during the experiment, could be the expression of proposed, beneficial impacts of targeted plyometric training on the effectiveness of the swimming start. However, at this stage of the study many intervening variables affecting the process under consideration were not taken into account. These include: positioning of the plyometric training for the swimming start in the athletes' annual training cycle, factors affecting planning and controlling of the training load, or aspects of individualisation of plyometric training in terms of age, level of skills and specialisation (style and distance) of swimmers. Thus, the significance of

formulated generalisations is limited. Nevertheless, this study provides a novel contribution regarding the use of plyometric training to enhance the performance of the swimming start. Subsequent studies, supported by profound empirical foundations, should provide information on the bioelectrical activity of muscles (EMG) during take-off and the structure of ground reaction forces during this phase of the swimming start.

## 5. Conclusions

Considering the limitations above, an attempt to identify the impact of a six-week plyometric training programme on the effectiveness of the swimming start (track-start) allowed to formulate the following conclusions.

1. It is possible that the impulses triggered by targeted plyometric training reduced start time and glide time and increased the average take-off, flight and glide velocities as well as the take-off, entry and glide instantaneous velocities. The glide angle was decreased.
2. Searching the areas of beneficial impacts of plyometric training on effectiveness of the swimming start confirmed the greatest importance of minimization of start time. Due to the possible impact of plyometric training on improvement of the start performance, the importance of the kinematics of glide phase (mainly minimisation of glide time) should be emphasized. Minimisation of glide angle and intensification of velocity in the take-off phase also seem to be an important factor influencing the improvement of the swimming start. One can also assume that a maximization of velocity at the last

moment of contact with the starting block and minimisation of the velocity reduction during entry in the water and in the glide phase start in the areas influenced by targeted plyometric training, aimed at enhancing the effectiveness of the swimming start.

3. Pertinence of the research procedures employed and confirmed diagnostic value of the results obtained suggest that the use of plyometric training directed at increasing take-off power caused changes in selected kinematic parameters of the swimming start in terms of improving its effectiveness.

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