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KINEMATIC ANALYSIS OF THE KICK START UNDERWATER PHASE OF YOUNG MALE SWIMMERS

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Authors' contribution:

A. Study design/planning
B. Data collection/entry
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E. Preparation of manuscript
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Abstract:

Introduction. The introduction of a starting block with an adjustable and slanted footrest has caused the development of a new starting technique - the Kick Start. Therefore, research on swim start seems necessary, particularly concerning the Kick Start underwater phase.

Aim. The study aim was to characterise the underwater phase of the Kick Start among young, male, competitive swimmers.

Basic procedures. The study included 32 male, youth, competitive swimmers (mean age=16.61 years, height=1.80 m, body mass=72.47 kg, FINA Points=617). Participants executed three freestyle Kick Starts recorded using an underwater high-speed camera. Videos were kinematically analysed using the Skill Spector programme. Then, k-means clustering was applied.

Results. Participants were classified into three clusters. Cluster FT ("flat trajectory") comprised swimmers with a "flat" course of underwater movement - low value of the angle of water attack ($K_A=0.92^{o}$), maximum depth of the head ($h_{max}=0.85$ m), distance ($d_{max}=0.71$ m), and time to maximum depth of the head ($t_{max}=0.51$ s). Group MT ("moderate trajectory") had moderate values of the above-mentioned parameters ($K_A=10.27^{o}$, $h_{max}=0.93$ m, $d_{max}=1.03$ m, $t_{max}=0.60$ s), while Cluster DT ("deep trajectory") achieved the highest values ($K_A=15.74^{o}$, $h_{max}=1.05$ m, $d_{max}=1.38$ m, $t_{max}=0.73$ s). The time to reach 15 m in Cluster FT was about 0.3 s slower than in Group MT and DT, although this dissimilarity was not significant.

Conclusions. The course of underwater movement is mostly affected by the angle at which swimmers submerge. There is no "ideal" way to perform the underwater phase, however, it should not be executed too close to the water surface.

Introduction

In a swimming race, phases such as the start, full style swimming and turns are most often distinguished [1]. The first of the mentioned components of the race - swimming start - begins with an audible start signal and ends when the competitor covers the first 15-m distance [2]. In the case of the front crawl, butterfly, breaststroke and individual medley races, the competitors start from the starting block, while in the case of the backstroke, the race starts in water. The discussed phase has significant impact on results in swimming, especially for sprint distances, i.e. 50-100 m [3]. It should not be surprising then, that many coaches and athletes pay a lot of attention to improving swimming start technique.

Until recently, there were two main techniques of swimming start from the starting block - Grab Start (the swimmer sets both feet on the front edge of the block) and Track Start (one foot set on the front edge of the block and the other at the back - like the crouch start in track-and-field). Both types of take-off have been the subject of many scientific studies, but it has not been clearly stated which technique allows to achieve a better time to reach 15 m [1].

In 2009, the rules of the World Swimming Federation changed in the area of construction and dimensions of starting blocks. An adjustable footrest (a so-called “kick plate”) was added at the back of the block, on which the foot of the rear limb can be supported [4]. The new way to start the race was called the Kick Start [5].

Based on research, it was found that the Kick Start allows to achieve a shorter start time than the Grab or Track Start [5]. Currently, the vast majority of swimmers prefer to start using the kick plate, which can be observed by analysing races at the most important swimming competitions - including from the 2016 Olympic Games in Rio de Janeiro. Due to the fact that the Kick Start is a relatively new starting variant, it has still not been studied in detail using, e.g. biomechanical methods as in the case of the two techniques earlier mentioned.

Technical analysis of swimming start is hindered by its complex structure. In training practice, to assess the quality of the start, the time is usually measured up to 15 m. This provides an overall image of the quality of the start, but does not provide complete information on the course of the athlete’s movement.

Assessment of swimming start performance using biomechanical analysis is more complex and uses more variables. During such tests, the swimming start is usually divided into parts. Most typically, there are: time on the starting block (start reaction time and push-off), flight and the underwater phase [3]. For many authors, even such a simplified division is, however, insufficient and they create an even more detailed distinction [1]. Until now, the authors of research on the Kick Start have mainly dealt with its first parts - movement on the starting block and flight. To characterize these elements, the most frequently chosen research method was kinematic analysis of video recordings [2]. On this basis, different types of starts with the use of a kick plate were described - the location criteria are the position of the centre of mass projection on the starting block and the way the body is positioned during flight [2]. It was found that there are several rules that should be followed by each athlete in order to make the push-off and flight most effective. Among them, the following were mentioned: assuming start position with appropriate knee flexion, maximising horizontal push-off velocity and adopting the most streamlined position before the end of the flight phase [2, 3]. At the same time, it was emphasized that it is difficult to unequivocally indicate one ideal movement pattern that would work for all athletes, which can be caused by individual differences between swimmers (e.g. in body composition or efficiency of underwater undulatory swimming) [1, 6].

Definitely less research on the Kick Start is related to its underwater phase. To date, the course of underwater movement has been fairly well characterised by world-class competitors [3]. As emphasized by Vantorre et al. [1] and Tor [3], in the case of the underwater phase, similarly as during the push-off and flight, the best swimmers present great variety in the course of movement at different depths of submersion, distance covered under water and movement path. On the basis of the abovementioned studies, however, several rules have been distinguished which competitors should follow in order to obtain the shortest start time. It was stated that after submerging the entire body, swimmers should remain in glide (so-called streamlined position without propelling their limbs) for about 2 s, and the start of underwater undulatory swimming cycle should take place at a distance of about 6.5 m from the starting wall [7, 8] . In addition, the maximum depth that a swimmer should reach is about 0.9-1 m, and most of the underwater part of the race should be covered at about 0.5 m below the water surface [3]. In the course of biomechanical research concerning the Kick Start, it has been noted that some kinematic indicators from the underwater part significantly affect the final start time, and, at the same time, are significantly determined by the course of the push-off and flight phases [1].

To date, no detailed research has been undertaken on the underwater part of the new swim start among a group of competitors with a sports level lower than world-class. However, it seems that the expansion of research regarding this issue, among others, for junior athletes, would allow to supplement the state of knowledge about this part of the swimming start. It may turn out that for competitors with a lower sports level, there are other strategies to achieve a shorter start time.

The purpose of this study was to characterise the underwater phase of the Kick Start among young male swimmers practicing competitive swimming.

The following hypotheses were verified:

1. In young swimmers, different movement patterns can be identified for the underwater phase of the swimming start.
2. The selection of the underwater movement trajectory does not affect the swimming start time needed to reach 15 m.
3. The course of movement under water is largely determined by the angle formed by the upper limbs and the water surface at the time of submersion.

Materials and methods

The study was conducted at the Indoor Swimming Pool of the University of Physical Education in Kraków in a 25-metre, 8-lane pool. The study group consisted of 32 male athletes practicing competitive swimming at Sports Championship Schools in Kraków and Oświęcim (age: 16.61 ± 0.76 years, body height: 1.80 ± 0.06 m, body mass: 72.47 ± 8.51 kg). The best average FINA score obtained by competitors up to 12 months before the test date was 617 ± 79 points [9].

All subjects agreed to participate in the measurements in the formula described below. In the case of underage athletes, written consent of their legal guardians was also obtained. On the day of measurements, each participant had a valid medical certificate entitling them to practice competitive swimming. The research was also approved by the Bioethics Committee at the Regional Medical Chamber in Kraków (permit number: 3/KBL/OIL/2018).

Before beginning the tests, the centre of the left shoulder joint was marked on the body of each subject in the streamlined position (upper limbs straight above the head, hand placed on hand). The markings were made on the side of the body using a black waterproof marker.

After a short warm-up on land and in water, and after several test swim starts, the proper measurement procedure began. The participants' task was to perform 3 swimming starts (Kick Starts) to freestyle in accordance with the applicable FINA swimming regulations. The subjects were instructed to perform a start reaching 15 m in the shortest possible time. Between each test, there was a short, 5-minute passive interval allowing full recovery.

The course of underwater movement was recorded with the Casio Exilim EX-FH25 camera in filming mode (recording frequency: 120 fps, shutter speed 1/200 s, resolution 640 x 480 pixels). The apparatus was placed behind the underwater window on a stationary tripod, at a depth of about 1 m below the water surface, at a distance of 5 m from the starting wall and 8 m from the lane on which the subjects swam. Using a vertical strip attached to the lane rope, a 5-m distance from the starting wall was marked, making it easier to position the camera. The aforementioned placement of the device made it possible to register an area with a range of over 7 m. Thanks to this, it was possible to record the submersion of the subjects and the underwater undulatory swimming.

The final setting of the camera was the result of tests aimed at minimising measurement error due to the occurrence of the refraction phenomenon. As part of the pilot study, an object of known length was placed vertically and horizontally in various places visible in the camera lens. On this basis, the distance between the camera and the underwater window was chosen at which the average error was the lowest - in the vertical plane this totalled 0.72%, while in the case of the horizontal plane, this equalled 0.79%.

At the same time, 15 m from the start wall, the Go Pro Hero 7 Black sports camera was placed (recording frequency: 120 fps, resolution 1920x1080, linear mode). The device was placed about 1.5 m above the water surface and about 6 m from the lane on which the subjects swam. This enabled the registration of the moment when the subject's head passed the 15-m point from the starting wall, and thus, ending the swim start phase.Synchronisation of both devices with the start signal was performed using the Swim Start Synchro system (Opti. Eng, Poland), created for the purposes of this research. The device simultaneously emitted a start sound signal (analogous to that used in swimming competitions) together with a light signal. Synchronised recording devices granted the additional possibility of measuring the time up to 15 m mark.

Recordings were analysed using the SkillSpector computer program. Firstly, one sample was selected for each subject, during which the shortest start time was obtained. Analysis of this recording was performed based on a 4-point body model (fingers of left hand, centre of rotation of the shoulder joint on the left side, forehead, toes of left foot). To scale the recordings, a calibration frame and a 5-m mark from the starting wall were used.

In Fig. 1, the division of the underwater phase into shorter fragments is presented. In accordance with the Tor method [3], it was assumed that the underwater part of the start began when the head touched the water surface. Submersion was complete when the whole body was under water. The next fragment was the glide - this lasted until the subject began a downward toe movement, which, in turn, marked the beginning of the underwater undulatory swimming.

Data from charts generated by SkillSpector were exported to MS Excel. According to the subdivision of the underwater phase described above, the following variables were calculated:

- t_{above} [s] – time of above-water phase – time from the start signal to the beginning of head submersion,
- d_{flight} [m] – flight length – the distance of the head from the starting wall at time of submersion,
- t_{sub} [s] – submersion time – time from forehead submersion to toe submersion,
- v_{sub} [m/s] – horizontal submersion velocity – average horizontal head velocity during submersion,
- K_A [°] – underwater attack angle – the angle between the horizontal and the long axis of the upper limbs at the time of submersion,
- h_{sub} [m] – depth in submersion – the depth at which the head was positioned when the toes were submerged,
- h_{max} [m] – maximal submersion depth – maximal depth at which the head positioned during the underwater phase,
- $h_{max\text{-}sub}$ [m] – vertical lowering of the head during full body submersion – displacement of the head from the time of full body immersion until reaching the maximal depth,
- t_{down} [s] – time of maximal head submersion – time from the head submersion until reaching its maximal depth,

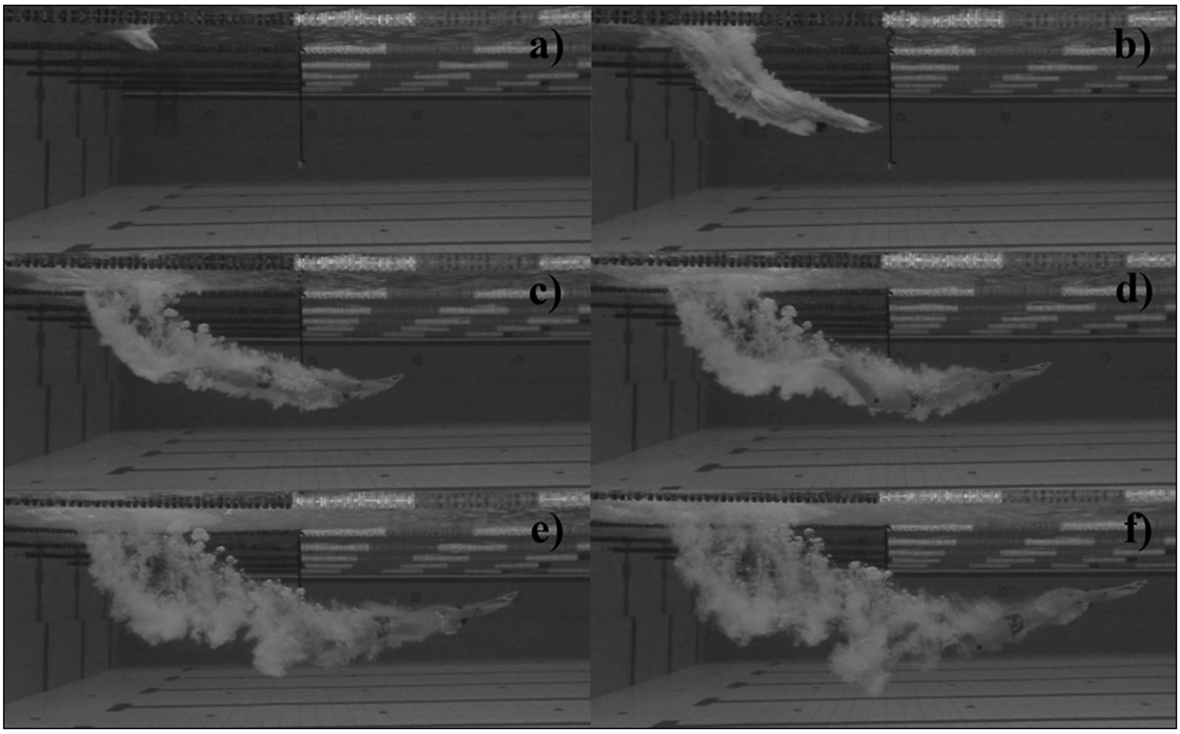

Fig. 1. Division of underwater phase into smaller fragments:

a) beginning of submersion (head submersion),
b) completion of body submersion, beginning of glide,
c) maximal head submersion, continuation of glide,
d) completion of glide, beginning of first underwater undulatory swimming cycle
e) lowest positioning of toes during underwater undulatory swimming cycle
f) highest positioning of toes, end of underwater undulatory swimming cycle

- $d_{max–sub}$ [m] – horizontal head displacement from the toe submersion until reaching maximal depth,
- t_{glide} [s] – glide time – from the fully submerged body until the toes begin to move downwards,
- d_{glide} [m] – glide length – horizontal displacement of the head from the full body submersion to the downward movement of the toes,
- v_{glide} [m/s] – average horizontal velocity during gliding,
- d_{UUS} [m] – underwater undulatory swimming starting point – horizontal distance from the starting wall,
- t_{UUS} [s] – underwater undulatory swimming cycle time – from the beginning of the downward movement of the toes until the end of the upward movement of the toes,
- v_{UUS} [m/s] – average horizontal velocity in the underwater undulatory swimming cycle,
- A_{UUS} [m] – amplitude of the underwater undulatory swimming – vertical displacement of the toes for the up and down movement during the underwater dolphin kicking cycle,
- t_{15} [s] – start time up to 15 m – from the start signal to the moment when the centre of the head passes the 15-m point from the start wall.

Measurement data was exported to the Statistica program. Firstly, the Grubbs Test ($p < 0.05$) was performed to eliminate outliers [10]. As a result of this analysis, 3 cases were identified from the initial number of 35 subjects, which were not included in this study. Then, the average, standard deviation and coefficient of variation of all kinematic indices and somatic features were calculated for the group of 32 participants. Next, cluster analysis was performed using the k-means method, sorting distances and selecting observations at a constant interval [11]. For the purposes of this study, a decision was made to divide the subjects into 3 groups, assuming 10 as the number of iterations. The next step in the statistical study was analysis of variance between the distinguished clusters, for which a significance level of $p < 0.05$ was adopted. As a result of the initial analysis, it turned out that the only differentiating factors regarded somatic features (height and mass). Due to the small dispersion of values within the area of somatic features, in the following cluster analysis, it was decided to eliminate them from the adopted model, retaining their other properties (number of groups, number of iterations, level of significance).

Results

As a result of cluster analysis, in the first group (cluster), there were 6 subjects, in the second - 10, and in the third - 16. The average values and standard deviations for each of the indices in the given clusters are presented in Table 1 together with the results of analysis of variance. Due to differences in the average values of some variables describing the course of underwater movement, the separated groups were termed as follows: the first - FT (“flat trajectory”), the second - MT (“moderate trajectory”), the third - DT (“deep trajectory”). Data included in Table 1 indicate that subjects from the DT group obtained the shortest start time up to 15 m ($t_{15} = 7.27$ s). They were faster than swimmers grouped in the MT ($t_{15} = 7.36$ s) and FT ($t_{15} = 7.60$ s) clusters by 1% and 4.5%, respectively. Although the absolute differences in t_{15} exceeded even 0.3 s, the results of analysis of variance did not allow to consider them as statistically significant.

In the case of above-water indices, the DT group subjects achieved a flight length longer (approx. 0.1 m) than swimmers from other clusters, with a very similar duration of the above-water phase (differences of 0.02 s between groups) and submersion time (differences of 0.01 s between groups). These discrepancies in the values of above-water indices of swimmers from individual groups were also not considered statistically significant.

Significant group-related differences were noted for submersion and glide indices. The absolute values of variables for which analysis of variance indicated significant differences between groups are marked in Table 1. Significant differences were noted, among others, in the underwater angle of attack (K_A) - the value of this vari-

Tab. 1. Descriptive statistics for each cluster along with results of variance analysis (F and p) between groups

	Variable	FT	MT	DT	F	*p*
	t_{15}	7.60 ± 0.32	7.36 ± 0.30	7.27 ± 0.41	1.74	0.19
Above-water indices	t_{above} [s]	1.25 ± 0.03	1.25 ± 0.10	1.23 ± 0.08	0.34	0.71
	d_{flight} [m]	3.01 ± 0.16	3.02 ± 0.15	3.12 ± 0.17	1.77	0.19
	t_{sub} [s]	0.30 ± 0.04	0.29 ± 0.04	0.29 ± 0.04	0.14	0.87
Submersion and glide indices	v_{sub} [m/s]	4.46 ± 0.31	4.57 ± 0.16	4.49 ± 0.26	0.43	0.65
	K_A [°]	**0.92 ± 3.73**	**10.27 ± 1.33**	**15.74 ± 1.82**	**104.79**	**0.00***
	K_A [°]	0.78 ± 0.16	0.80 ± 0.12	0.83 ± 0.14	0.38	0.69
	h_{max} [m]	**0.85 ± 0.18**	**0.93 ± 0.14**	**1.05 ± 0.15**	**4.25**	**0.02***
	$h_{max-sub}$ [m]	**0.07 ± 0.04**	**0.13 ± 0.04**	**0.22 ± 0.08**	**13.331**	**0.00***
	t_{down} [s]	**0.51 ± 0.17**	**0.60 ± 0.11**	**0.73 ± 0.15**	**6.11**	**0.01***
	$d_{max-sub}$ [m]	**0.71 ± 0.49**	**1.03 ± 0.25**	**1.38 ± 0.40**	**7.68**	**0.00***
	t_{glide} [s]	0.36 ± 0.13	0.41 ± 0.17	0.35 ± 0.14	0.49	0.62
	d_{glide} [m]	1.08 ± 0.32	1.26 ± 0.39	1.11 ± 0.40	0.55	0.58
	v [m/s]	3.05 ± 0.24	3.19 ± 0.30	3.26 ± 0.26	1.32	0.28
Underwater undulatory swimming indices	d_{UUS} [m]	5.41 ± 0.40	5.59 ± 0.42	5.55 ± 0.39	0.39	0.68
	t_{UUS} [s]	0.42 ± 0.06	0.43 ± 0.07	0.43 ± 0.08	0.01	0.99
	v_{UUS} [m/s]	2.18 ± 0.17	2.25 ± 0.29	2.43 ± 0.26	2.79	0.08
	A_{UUS} [m]	0.58 ± 0.08	0.59 ± 0.09	0.57 ± 0.09	0.14	0.87

* - $p < 0.05$

able for swimmers with a flat trajectory oscillated around 0°, among competitors with moderate trajectory, this was about 10°, while in the case of subjects from the cluster, this totalled approximately 15°. In order to better illustrate the discrepancy in the values of indices recorded in the groups, a figure was constructed in which the described values were expressed in percentages (the values of variables from the group with the shortest start time - DT - were assumed as 100%). These results are presented in Fig. 2.

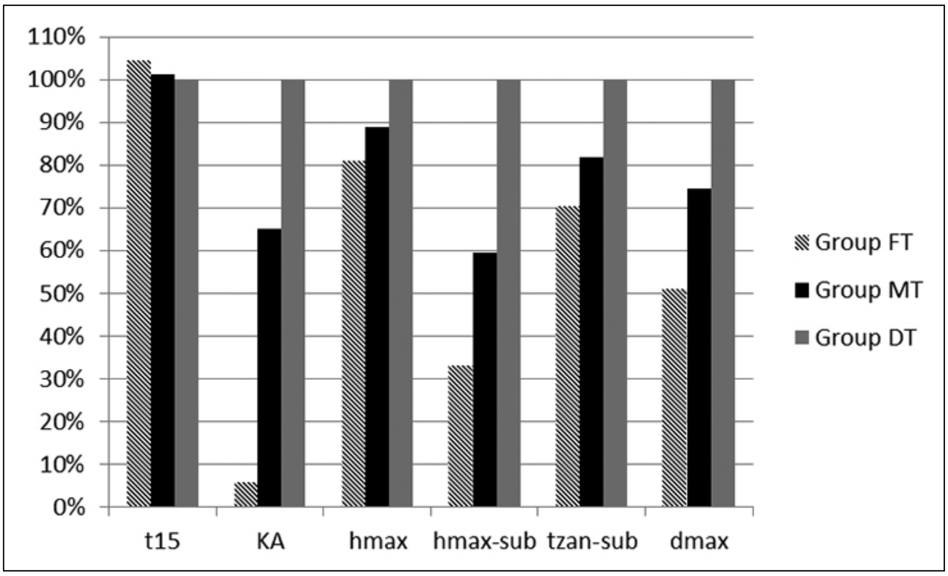

Fig. 2. Values of selected indices describing the start for groups in percentages (the value for the group with the shortest start time – DT - was assumed as 100%)

Swimmers with deep trajectory reached almost twice as high values of horizontal head displacement from the point of full body submersion until reaching the maximal depth ($d_{max\text{-}sub} = 1.38$ m) compared to subjects with a flat trajectory ($d_{max\text{-}sub} = 0.71$ m). This variable among the subjects from MT was about 1 m. Similarly as in the case of KA, the mentioned average $d_{max\text{-}sub}$ values demonstrated statistically significant differences.

Significant disproportion was also noted in the vertical lowering of the head during full-body submersion ($h_{max\text{-}sub}$) - in this case, subjects with a flat trajectory reached 33%, and swimmers with an moderate trajectory: 59% of the values noted among swimmers from the DT cluster. Slightly smaller group-related differences ($p < 0.01$), although still statistically significant, were found for the time of maximal head submersion (t_{down}). The described variable reached the highest values in the DT group, while among the subjects with flat and moderate trajectories, this was lower by about 30% and 20%, respectively. For maximal submersion depth $_{(hmax)}$, the highest values were recorded for the DT group swimmers (1.05 m). In other groups (MT and FT), this variable was clearly lower (by 11% and 19%, respectively). Analysis of variance showed that the differences between the groups were significant at the adopted statistical level ($p = 0.02$).

As in the case of indices for the above-water part of the start, for variables describing underwater undulatory swimming, no significant differences were noted between groups. The variable closest to the significance threshold ($p = 0.08$) was the average horizontal velocity during underwater undulatory swimming cycle (v_{UUS}), for which the values of subjects from the FT, MT and DT groups were 2.18 m/s, 2.25 m/s and 2.43 m/s, respectively. Analysis of the results for the remaining indices from the underwater undulatory swimming cycle did not suggest significant group-related differences.

Discussion

The results of this study indicate that young swimmers present a great variety in the course of the underwater phase of the swimming start. In the FT group (flat trajectory), there were competitors with "shallow" trajectory - low values of the underwater attack angle ($K_A = 0.92°$) and a small submersion depth (h_{max}), small vertical lowering of the head during full-body submersion ($h_{max\text{-}sub}$), a short time to reach maximal head submersion (t_{down}) and a slight level of head displacement to reach maximal depth ($d_{max\text{-}sub}$). It was also noted that swimmers from this group reached the lowest velocity during underwater undulatory swimming cycle.

The MT group (moderate trajectory) clustered swimmers with average values of indices describing the underwater trajectory. First of all, with the underwater attack angle of about 10°, the swimmers from this group submerged deeper by about 0.08 m compared to subjects from the FT group. In the case of swimmers with moderate trajectory, the $h_{max\text{-}sub}$, t_{down} and $d_{max\text{-}sub}$ indices assumed higher values in comparison to flat trajectory subjects. This means that discrepancies in the values of the underwater attack angle between the subjects from the FT and MT groups were the reason for the differences between the distinguished groups regarding the aforementioned indices.

In the final group - DT (deep trajectory) - there were swimmers with the by far greatest underwater attack angle ($K_A = 15.74°$). In the case of those tested, high values of maximal submersion depth ($h_{max} = 1.05$ m) also resulted in higher values of the $h_{max\text{-}sub}$, t_{down} and $d_{max\text{-}sub}$ indices. This means that subjects from the given group submerged the deepest. At the same time, the disproportions given in the values of indices describing the underwater trajectory between the DT, FT and MT groups did not result in significant differences in start time up to 15 m.

According to many authors, the underwater phase has significant impact on the time of swimming start [1, 8, 11]. There are two reasons for this - above all, this fragment is the longest-lasting part of the start phase [2]. At the same time, it is an element of the race that the competitors cover the fastest [3]. The high speed of swimmers translates into possibly experiencing significant resistance forces during the underwater part of the start [8]. This means that the swimmer's goal during this phase of the race should be primarily to minimise drag forces. Otherwise, mistakes made during the underwater phase result in a significant decrease in speed, having a noticeable effect on the final result in a sprint race [3].

Some authors indicate that the course of the underwater phase is largely determined by push-off and flight [2]. In this work, there were no significant differences in t_{above} and d_{flight} between swimmers from the selected groups. It is worth noting, however, that among the DT group swimmers, the shortest time of the above-water phase (t_{above}) and, at the same time, the longest flight (d_{flight}) was noted, which indicates a higher horizontal velocity in this fragment, which is probably the effect of more effective push-off of the deep trajectory subjects. This small advantage of swimmers from this group in the initial part of the start could lead to slightly more pronounced group-related disparities in the indices of the underwater phase and t_{15}. This means that the values of variables from the initial stages of the start should be carefully analysed, because they can affect the course of movement in further parts of the race, which was described, among others, by Vantorre et al. [1].

Until now, the authors of research mainly focused on the angle that the body creates with the water surface at the end of the flight (determined by contact between fingers and water). According to Vantorre et al. [1], the speed achieved by a competitor in submersion after the start is largely determined by the way the swimmer sets his/her body relative to the water surface in the air. In the study, focus was on the angle of attack noted below the water surface. It turned out that the discussed index had significant impact on the variables describing the underwater part of the start (h_{max}, $h_{max\text{-}sub}$, t_{down}, $d_{max\text{-}sub}$), and as a consequence, this turned out to be key in assigning the subjects to specific clusters.

Due to the considerable resistance affecting competitors at the initial parts of the underwater start phase, analysis of the underwater angle should be an integral part of the analysis of this part of the race [8]. As previously mentioned, at the time of submersion, competitors move at a speed that they are unable to achieve by swimming full styles [7]. In addition, due to the high speed and movement close to the water-surface, significant wave resistance may affect the subjects. This kind of observation was noted by, among others, Vennel et al. [13]. They found that the value of wave resistance decreases with depth, therefore, swimmers moving on a flat trajectory may be affected by a greater drag force than competitors using the moderate or deep trajectory. For the above reasons, researchers dealing with the underwater part of the start [3, 13] indicate that the maximum depth to which swimmers should submerge is about 1 m below the water surface, while the greater part of the underwater phase (glide, underwater undulatory swimming) should be performed at a depth of about 0.5 m. At the same time, the desired horizontal direction of movement should be observed, ensuring that the vertical displacement does not exceed the necessary minimum.

It was noticed that the subjects from individual groups did not differ significantly during the swim start to reach 15 m. At the same time, it should be emphasized that the subjects from the FT group, at a similar submersion velocity, moved the slowest during the glide phase (differences of 0.14-0.21 m/s relative to MT and DT) and during the performance of underwater undulatory swimming cycle (differences of 0.07-0.25 m/s relative to those remaining). In the case of competitors with a flat trajectory, the underwater attack angle may be so small that the subjects from this group moved too close to the water surface later in the start. This, in turn, led to a slightly greater decrease in speed under water and a longer take-off time to reach 15 m in comparison to subjects from other groups.

Maintaining high speed in the underwater part of the start is favoured by the right time to start the underwater undulatory swimming . The transition from glide to propelling using lower limb should begin when the velocity of the swimmer decreases to approx. 1.9-2.2 m/s [8]. Elipot et al. [7] and Tor [3] indicate that this usually occurs when the competitor's head is about 6-6.5 m from the starting wall. In this study, competitors from each group began propelling using underwater undulatory swimming within the range of 5.41-5.59 m. This discrepancy with respect to the "ideal" values noted by Tor [3] could have been due to both the different sports level of the studied groups (the author analysed starts of high-class competitors), as well as from different methodology - in this study, it was assumed that the beginning of the underwater undulatory swimming cycle took place when the subject began to move his toes downwards. The publication cited above did not contain information on how to determine the beginning of underwater undulatory movements.

Conclusions

Based on the results of this study, the hypotheses were verified and the following conclusions were formulated:

1. Young swimmers present great variety of movements during the underwater part of the swimming start. Three main patterns of the underwater phase may be distinguished - flat, moderate and deep trajectory.
2. Choosing a too flat movement trajectory at the initial fragment of the underwater phase may result in achieving a longer take-off time to reach to 15 m.
3. The course of movement under water is significantly related to the angle formed by the upper limbs relative to the water surface at the time of total submersion.

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