



KINEMATIC ANALYSIS OF ABOVE- AND UNDERWATER SWIM START PHASES OF MALE SWIMMERS AGED 16–18 YEARS

original paper

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ABSTRACT

Purpose. Swim start technique analysis is usually conducted in elite swimmers or only limited to above-water phases. The aim of the study was to analyse kinematic parameters of above- and underwater kick start phases among young male swimmers.

Methods. The study group comprised male swimmers (FINA points per 100-m freestyle: 525 ± 84). The subjects performed a 15-m front crawl with kick start. The trials were recorded above and below water with 3 recording devices synchronized with the starting signal. Kinematic analysis by using 2 models (above- and underwater) of body was done. On the basis of time to cover 15 m, 2 groups were distinguished: quickly (FS) and slowly (SS) performing the swim start.

Results. FS and SS demonstrated differences ($p < 0.05$) regarding hip joint height at starting signal (1.56 ± 0.05 m vs. 1.45 ± 0.05 m), push-off angle ($23.89 \pm 6.50^\circ$ vs. $35.12 \pm 3.43^\circ$), hip joint angle upon completing push-off ($163.83 \pm 8.37^\circ$ vs. $149.73 \pm 9.93^\circ$), and horizontal velocity during flight (3.70 ± 0.35 m/s vs. 3.24 ± 0.22 m/s), submersion (4.88 ± 0.09 m/s vs. 4.36 ± 0.22 m/s), and glide phase (3.40 ± 0.17 m/s vs. 2.99 ± 0.29 m/s).

Conclusions. The obtained results indicate that position on the block significantly influences the movement course in consecutive phases. Young competitors should aim towards elevated hip positioning, allowing to maximize horizontal velocity during the flight, submersion, and glide phases.

Key words: biomechanics, youth sport, swimming

Introduction

The current level of technological development allows for a very broad utilization of computers in the training process. They are implemented, among others, in the kinematic analysis of swimming movements. Such assessment of the technique is also favoured by the popularization of high-quality recording equipment. The main advantage of motion analysis based on video material is that placing instruments on the tested subject's body becomes unnecessary. Thanks to this, there is no interference in the natural course of the assessed movement [1].

However, reliable measurement with underwater film recordings is a complex task [2]. There are many factors to be considered when creating the evaluation procedure, e.g. the recording device has to be placed in a waterproof housing or behind an underwater win-

dow and thus the phenomenon of refraction has to be taken into account [3]. The aforementioned methodological limitations mean that in biomechanical studies involving the calculation of simple kinematic indices (e.g. average speed of several-metre long sections, length of a swimming stroke, or frequency), placing cameras below the water surface is infrequently implemented, and the technique is characterized only on the basis of above-water movements [4]. The same is done in the case of swim start analysis, often limited only to the phases visible above the water [5–7]. With the recordings of these fragments of the swim start, it was found, among others, that the latest technique of performing this element, the kick start (performed with the so-called back plate), helped reduce the start time more efficiently than older techniques (track or grab start) [8]. Using the back plate enables more optimal positioning of the rear limb during push-off, thereby in-

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creasing the value of the horizontal component of contact force on the starting block [5, 9]. Moreover, starting with the use of the back plate helps reduce the time spent on the starting block [5]. It is also important that the back plate ensures greater body stability after the 'take your mark' command [10].

It is assumed that the swimming start begins with the start signal and lasts until the swimmer completes the first 15 m of the race [11]. As indicated by Tor et al. [12], the phases in which the movement is partially or completely carried out in the water – submersion, glide, and underwater dolphin kicking (so-called underwater undulatory swimming) – have a significant impact on the final start time of swimming. The start description taking only its above-water part into account is therefore incomplete.

Previous studies on the above- and underwater part of the start were mainly limited to the description of the track and grab start [13, 14]. Until now, publications on the kick start have focused on relatively simple kinematic indices [15]. Therefore, some variables (e.g. depth of submersion, changes of underwater attack angle) are not extensively described. Moreover, the majority of studies dealt with groups of swimmers representing the highest sports level [12, 14–16]. Research on this issue should not, however, be limited only to adults, shaped by many years of the training process. According to Silva et al. [17], the determinants of sports success in adolescence may differ from those in adulthood. Therefore, the idea of creating an 'expert concept' for this age group based on research results with adult world-class athletes is incorrect [17]. At the same time, this means that research involving young swimmers has high applicative value. Their results may exert a greater impact on optimizing the technique among competitors, e.g. at the level of juniors, than measurements carried out among world-class swimmers.

The main purpose of this study was to assess the kinematic differences in the kick start indices among groups of young competitors performing this element faster and slower. On this basis, differences in the kick start technique were sought in the context of the athletes' start time until covering the first 15 m.

Material and methods

The research was carried out at the Indoor Swimming Pool Complex of the University of Physical Education in Krakow. The measurements were conducted on a 25-m long, 8-lane pool (pool depth of 2–2.5 m) equipped with Omega OSB11 starting blocks enabling the execution of the kick start.

The study group consisted of 20 male swimmers from Sports Championship Schools in Krakow and Oswiecim (mean age: 16.83 ± 0.80 years, body height: 1.80 ± 0.06 m, body mass: $= 72.2 \pm 8.4$ kg). The swimmers represented varying distance and stroke specializations. The average FINA point score for 100-m freestyle in a short-course pool obtained by the subjects during the 12 months preceding the research was 525 ± 84 points. Before the beginning of the tests, the swimmers were informed about the measurement procedure. They were also instructed that they could withdraw from testing at any stage of the trial.

Proper research was preceded by the collection of anthropometric data in accordance with the methodology developed by Martin and Saller [18] and Tanner [19]. An anthropometer from the Sieber Hegner Machines SA production set (GPM, Switzerland), a skinfold calliper (GPM, Switzerland) with a constant pressure of 10 g/mm^2 , and Tanita BC-418 (Tanita, Japan) electronic scales were used. The following were measured: body height to the nearest 0.001 m and body mass to the nearest 0.1 kg. The thickness of triceps and subscapular skinfolds (to the nearest 0.5 mm) was also assessed. This enabled the determination of body fat levels by using the formula created by Slaughter et al. [20]:

$$B_F = 1.21 \times (F_A + F_S) - 0.008 \times (F_A + F_S)^2 - f$$

where: B_F – body fat, F_A – fold on triceps, F_S – fold on shoulder blade, $f = 5.5$ (constant for post-pubertal phase).

Then, in accordance with the methodology presented by Wądrzyk et al. [21], characteristic anatomical points were marked on the participants' bodies with a black waterproof marker. Their indication enabled mapping of the transverse axis of the upper ankle, hip, knee, and shoulder joints.

Before the beginning of the study procedure, a standard 10-minute warm-up on land, including standard exercises of the RAMP protocol (raise, activate, mobilize, potentiate), was conducted. After a 15-minute in-water warm-up supervised by the subjects' coach (total volume of ca. 800–1000 m), the participants performed a series of test starts. After a break of ca. 10 minutes, each subject performed 3 kick starts (with the rear limb positioned on the plate) to front crawl. The tests were carried out in accordance with FINA swimming regulations, including start commands. The participant's task was to pass the 15-m line from the starting wall as quickly as possible. To enable full recovery of the subject's condition between the trials, ca. 5 minutes of passive break were given before each test.

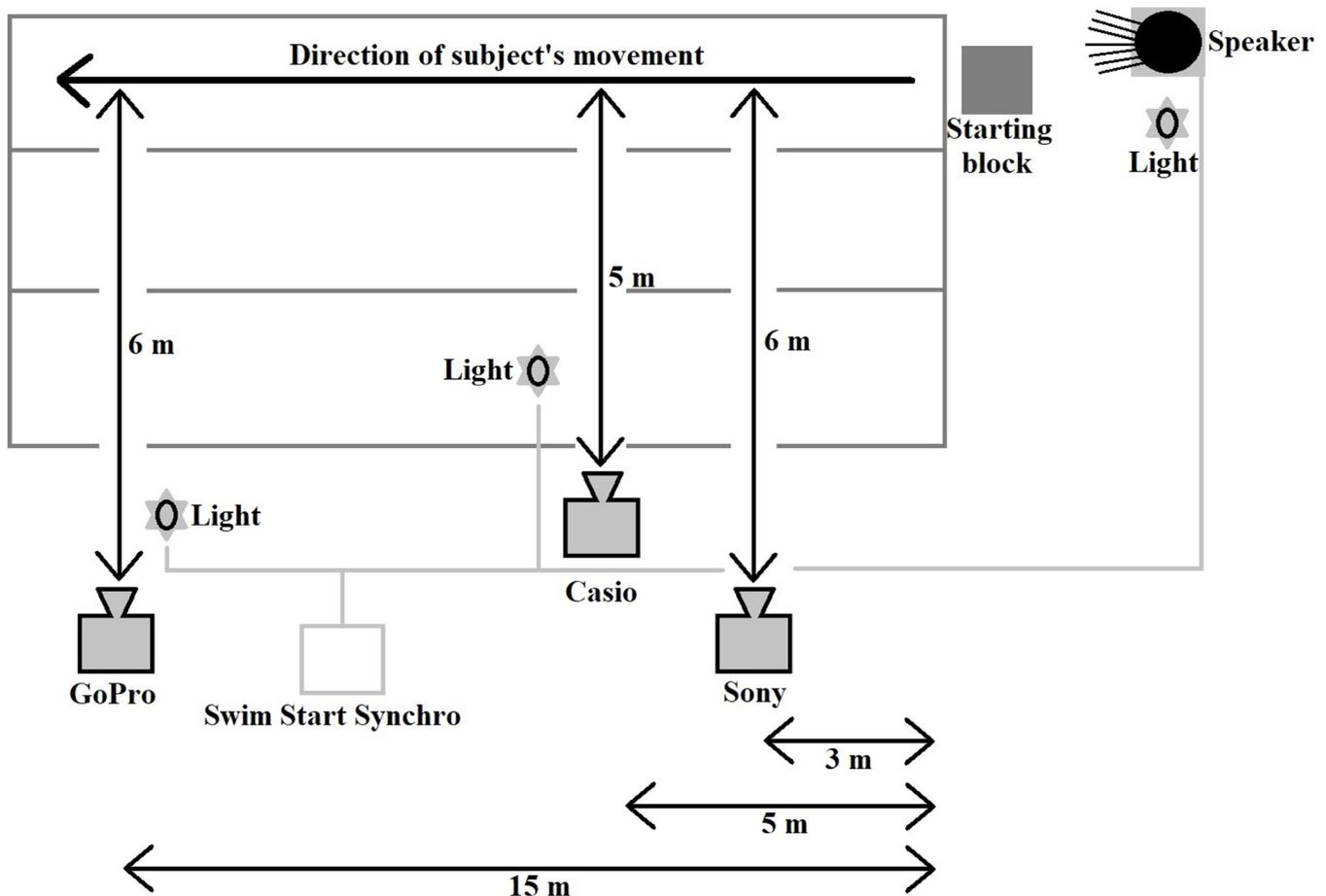


Figure 1. The filming set-up of the 3 digital video cameras and synchronized starting system

The swimming starts were filmed by using 3 recording devices: Sony DSC-RX100M3, Casio Exilim EX-FH25, and GoPro Hero Black 7. Their arrangement is shown in Figure 1. The Sony camera was set to record the overwater part of the movement – from the start signal to total submersion of the subject under water. The Casio apparatus was placed behind the underwater window in a way allowing to record the movement from finger submersion to performing one full cycle of underwater dolphin movement, taking the phenomenon of refraction into account. The GoPro camera was located above the water, on a line 15 m from the starting wall. The same mode of filming with the same recording frequency (120 frames/s) was applied for all the devices. The cameras and video recorders were synchronized by using the Swim Start Synchro system (Opti.Eng, Poland). The device emitted a start sound together with 3 light signals visible in the lenses of the recording equipment.

From among the 3 trials performed by each of the subjects, the one with the shortest start time up to the 15-m mark (t_{15}) was selected for further analysis. The SkillSpector computer program was used to determine

kinematic indices. The analysis of recordings regarding above-water movements was based on a 6-point model in accordance with the methodology presented earlier by Wądrzyk et al. [21]. In turn, a 4-point body model (5th finger of the left hand, centre of rotation of the shoulder joint on the left side, forehead, 5th toe of left foot) was used to characterize the course of underwater movements. Both cameras were calibrated with a 1.02-m square frame. The mean error in length for a 2-m long object totalled 0.76%.

Data from charts generated in the SkillSpector program were exported to MS Excel. The kinematic indices are presented in Table 1.

Statistical analysis of data was performed with the Statistica program. First, the arithmetic means (\bar{x}) and standard deviations ($\pm SD$) of start times (t_{15}) were calculated for the whole group. On this basis, 2 groups were created: faster starters (FS) and slower starters (SS). The participation in groups was determined by the individually recorded start time. When it was shorter than the group average minus the SD value ($t_{15} \leq \bar{x} - SD$), the examined subjects were classified into the FS group. In the case of achieving a time

Table 1. Names of the variables

Variable	Unit	Names
Starting block phase	t_{15}	s Start time – from the starting signal until the middle of the head reaches a distance of 15 m
	H_{Hip}	m Height of hips on block – hip height with respect to water surface
	$A_{FrontKnee}$	° Angle in knee joint of front limb at time of starting signal
	$A_{RearKnee}$	° Angle in knee joint of rear limb at time of starting signal
	t_{Block}	s Time of starting block – from time of starting signal to front limb loss of contact with block
	$A_{Pushoff}$	° Push-off angle – angle between horizontal line and biomechanical axis of front limb at time of loss of contact with the block (apex – centre of talocrural joint)
	$A_{HipPushoff}$	° Angle in hip joint of rear limb at time of completing push-off
	$H_{HipPushoff}$	m Height of hip joint with respect to water surface at time of loss of contact with block
Flight phase	t_{Flight}	s Flight duration
	d_{Flight}	m Flight length – horizontal distance of place of head submersion from starting wall
	v_{Flight}	m/s Flight velocity – mean horizontal head velocity at time from loss of contact with starting block to submersion of head in water
	$A_{AttackAbove}$	° Above-water attack angle – between line of water surface and upper limb at time of contact of fingers with water (apex – thumb of left hand)
	A_{HipSub}	° Angle in hip joint at time of finger contact with water
	H_{HipSub}	m Hip height at flight completion – height of hip joint with respect to water surface at time of head submersion
Underwater phase	t_{Sub}	s Time of submersion – from head contact with water to submersion of toe
	v_{Sub}	m/s Submersion velocity – mean horizontal head velocity from head contact with water to submersion of toe
	$A_{AttackSub1}$	° First underwater attack angle = between water surface and upper limb at time of glenohumeral limb submersion (apex – middle of left glenohumeral joint)
	$A_{AttackSub2}$	° Second underwater attack angle – between level and upper limbs at time of toe submersion (apex – middle of left glenohumeral joint)
	t_{Glide}	s Glide duration – from time of toe submersion to beginning of their downward movement, initiating lower limb underwater dolphin kicking movement
	d_{Glide}	m Glide length – horizontal head displacement during glide phase
	v_{Glide}	m/s Glide velocity – mean horizontal head velocity during glide phase
	h_{Max}	m Maximal depth of head submersion with respect to water surface
	d_{Max}	m Horizontal distance from starting wall to place of achieving maximal depth of submersion with respect to water surface
	d_{UUS}	m Place of beginning underwater dolphin kicking movement (distance from starting wall)
	R_{UUS}	m Amplitude of feet during first underwater dolphin movement
	t_{UUS}	s Duration of first dolphin kicking cycle
	v_{UUS}	m/s Mean horizontal head velocity during first dolphin kicking cycle

longer than the sum of the arithmetic mean and *SD* ($t_{15} \geq \bar{x} + SD$), the subject was included in the SS group. The values of basic descriptive characteristics were calculated in both separate sets. The Mann-Whitney U test was used to determine the significance of differences in the level of kinematic indices between the FS and SS groups, assuming the statistical signifi-

cance of the results at $p < 0.05$ [22]. Furthermore, Cohen's *d* effect size calculations with correction for a nonparametric statistical test were performed [23]. An analogous approach was taken to describe differences between groups regarding sports level (FINA points), age, body height, body mass, and body fat.

Ethical approval

The research related to human use has complied with all the relevant national regulations and institutional policies, has followed the tenets of the Declaration of Helsinki, and has been approved by the Bioethical Commission at the Regional Medical Chamber in Krakow (consent No.: 3/KBL/OIL/2018).

Informed consent

Informed consent has been obtained from all individuals included in this study. In the case of underage athletes, consent for participation was obtained from their legal guardians.

Results

Considering all of the subjects, the average time to cover the first 15 m (t_{15}) was 7.38 s ($SD = 0.34$). On this basis, participants with start times shorter than 7.04 s were assigned to the FS group. This condition was met by 6 competitors. In turn, subjects for whom the $t_{15} > 7.72$ s condition was met, were included in the SS group. There were 5 swimmers in this group.

Comparing the groups in terms of differences in somatic build and sports level, it was found that the athletes in the FS group were heavier than those in the SS group (79.48 kg and 62.34 kg, respectively) and also obtained better results for 100-m freestyle (FINA points: 628 and 489, respectively). The mentioned differences turned out to be significant. For other anthropometric variables (body height, body fat level), as well as for age, no such differences were noted. The list of average values of these variables in the distinguished groups is presented in Table 2. In turn, the descriptive characteristics of kinematic indices together with the values regarding the significance level of differences and effect size between sets are presented in Table 3.

According to the methodological assumptions, the inclusion criterion for the study groups was the time from the starting signal to reaching the 15-m mark.

The mean difference in t_{15} between the SS and FS groups was nearly 1 s (values of 6.94 s in the FS and 7.88 s in the SS group).

Of all the variables describing the phase on the starting block in the FS and SS groups, only 3 were significantly different. The mean difference in the height of hip placement on the starting block (H_{Hip}) between the FS and the SS group was 0.11 m. Competitors obtaining a shorter start time were also characterized by a flatter push-off from the starting block than representatives of the SS group. Push-off angle values ($A_{Pushoff}$) recorded in the 2 groups differed by an average of 11° . The difference of means in the angle in hip joint at time of the contact of the finger with water surface was ca. 14° . It is worth noting that the average values of selected variables ($A_{FrontKnee}$, t_{Block} , $H_{HipPushoff}$) differed by more than 7%, but the analysis did not show any significance of these differences.

Slight differences between groups were also observed during the flight phase. The only variable for which significant disproportions between the FS and the SS group were revealed was horizontal flight velocity (v_{Flight}) (mean difference: about 0.5 m/s).

The mean horizontal velocity during the submersion (v_{Sub}) and glide (v_{Glide}) phases were the only indices characterizing the underwater phase for which significant differences between the groups were demonstrated. In the case of the former, the mean disproportion in favour of the FS group was 0.5 m/s, while for the latter, it oscillated around 0.4 m/s. The level of the remaining underwater phase indices – describing submersion, glide, as well as the underwater dolphin cycle – did not differ in the compared groups.

Among all of the variables, the highest Cohen's d values were found for t_{15} and v_{Sub} . The size effect for most indicators was large (> 0.8). However, these results should be taken into account with caution owing to the small numbers of groups. For very few variables (H_{HipSub} , $A_{AttackSub1}$, t_{Glide}) the size effect was small.

Table 2. Anthropometric characteristics and sports level of faster starters (FS) and slower starters (SS)

Variable	Name	FS ($\bar{x} \pm SD$)	SS ($\bar{x} \pm SD$)	p	Effect size
Number (n)		6	5	–	–
A (years)	Age	17.47 ± 0.62	16.73 ± 0.59	0.083	1.319
P_{FINA} (–)	FINA points (sports level)	629 ± 65	589 ± 56	0.008	2.928
B_H (m)	Body height	1.84 ± 0.09	1.76 ± 0.05	0.121	1.141
B_M (kg)	Body mass	79.48 ± 10.47	62.34 ± 7.99	0.022	2.049
B_F (%)	Body fat	9.58 ± 2.62	9.92 ± 2.79	0.784	0.222

Table 3. Kinematic indices of faster starters (FS) and slower starters (SS)

Variable	Name	FS ($\bar{x} \pm SD$)	SS ($\bar{x} \pm SD$)	<i>p</i>	Effect size	
Starting block phase	t_{15} (s)	Start time	6.94 ± 0.08	7.88 ± 0.09	0.008	2.928
	H_{Hip} (m)	Height of hips on block	1.56 ± 0.05	1.45 ± 0.05	0.018	2.221
	$A_{FrontKnee}$ (°)	Angle in knee joint of front limb at time of starting signal	132.32 ± 12.95	119.81 ± 9.71	0.171	0.981
	$A_{RearKnee}$ (°)	Angle in knee joint of rear limb at time of starting signal	90.47 ± 9.07	87.25 ± 6.81	0.523	0.451
	t_{Block} (s)	Time of starting block	0.83 ± 0.04	0.89 ± 0.09	0.235	0.835
	$A_{Pushoff}$ (°)	Push-off angle	23.89 ± 6.50	35.12 ± 3.43	0.022	2.049
	$A_{HipPushoff}$ (°)	Angle in hip joint of rear limb at time of completing push-off	163.83 ± 8.37	149.73 ± 9.93	0.036	1.760
	$H_{HipPushoff}$ (m)	Height of hip joint with respect to water surface at time of loss of contact with block	1.22 ± 0.10	1.34 ± 0.04	0.100	1.227
Flight phase	t_{Flight} (s)	Flight duration	0.32 ± 0.08	0.39 ± 0.03	0.171	0.981
	d_{Flight} (m)	Flight length	2.92 ± 0.22	2.80 ± 0.15	0.315	0.700
	v_{Flight} (m/s)	Flight velocity	3.70 ± 0.35	3.24 ± 0.22	0.022	2.049
	$A_{AttackAbove}$ (°)	Above-water attack angle	39.98 ± 10.48	43.54 ± 1.70	0.648	0.335
	A_{HipSub} (°)	Angle in hip joint at time of finger contact with water	166.14 ± 13.08	172.37 ± 10.34	0.411	0.573
	H_{HipSub} (m)	Hip height at flight completion	0.64 ± 0.04	0.65 ± 0.08	0.927	0.110
Underwater phase	t_{Sub} (s)	Time of submersion	0.30 ± 0.02	0.28 ± 0.05	0.315	0.700
	v_{Sub} (m/s)	Submersion velocity	4.88 ± 0.09	4.36 ± 0.22	0.008	2.928
	$A_{AttackSub1}$ (°)	First underwater attack angle	33.08 ± 5.16	32.48 ± 3.94	0.927	0.000
	$A_{AttackSub2}$ (°)	Second underwater attack angle	15.75 ± 3.50	15.31 ± 7.66	0.648	0.335
	t_{Glide} (s)	Glide duration	0.43 ± 0.11	0.48 ± 0.26	1.00	0.055
	d_{Glide} (m)	Glide length	1.46 ± 0.33	1.38 ± 0.61	0.411	0.573
	v_{Glide} (m/s)	Glide velocity	3.40 ± 0.17	2.99 ± 0.29	0.036	1.760
	h_{Max} (m)	Maximal depth of head submersion with respect to water surface	1.05 ± 0.13	1.11 ± 0.11	0.523	0.451
	d_{Max} (m)	Horizontal distance from starting wall to place of achieving maximal depth of submersion with respect to water surface	1.50 ± 0.55	1.33 ± 0.52	0.648	0.335
	d_{UUS} (m)	Place of beginning underwater dolphin kicking movement	5.93 ± 0.46	5.57 ± 0.55	0.315	0.700
	t_{UUS} (s)	Duration of first dolphin kicking cycle	0.48 ± 0.11	0.46 ± 0.09	0.584	0.393
R_{UUS} (m)	Amplitude of feet during first underwater dolphin movement	0.71 ± 0.14	0.58 ± 0.06	0.144	1.059	
v_{UUS} (m/s)	Mean horizontal head velocity during first dolphin kicking cycle	2.34 ± 0.10	2.14 ± 0.32	0.121	1.141	

Discussion

Although research on swim starts has been regularly conducted since the late 1960s, it was only after 2009 that interest in this element of the race significantly increased. Changes in swimming regulations enabling the use of the back plate gave rise to commencing research on determining the way of starting a race (grab, track, or kick start) that would allow to obtain the shortest time to cover the first 15-m distance. The authors of publications on the subject agree that the kick start technique is currently the most effective way to begin a race [5–6]. These facts mean that the kick start is fundamentally different from older starting techniques during the block, flight, and underwater phases [15]. It has also been suggested that the effectiveness of kick start (in particular its initial phases) may be determined by different kinematic indicators than grab and track start. This concerns mainly the position of the back foot on the back plate, which favours force development in the desired direction [24]. The authors decided to refer the results of this study only to research in which the subject of analysis was the kick start, although this is not a frequent procedure [10–11].

The comparison of the FS and SS groups in terms of the position assumed on the starting block revealed that the hips of the FS subjects were higher than those of the SS group representatives. There were probably 2 factors behind this. The first one was different somatic build – FS swimmers were taller than the subjects from the SS group and therefore their lower limbs were probably longer. Although the differences in body height between the groups were not significant, as were the disparities of the angle values recorded in the knee joint of the front limb ($A_{\text{FrontKnee}}$ greater by about 13° in FS), it is probable that their combined effect resulted in a significantly higher hip position among FS athletes. As indicated by Slawson et al. [7], the optimal angle in the knee of the front limb is $135\text{--}145^\circ$. These values not only ensure a sufficiently high position of the hips, but also allow the knee and hip extensor muscle groups to generate optimal force. It has been proven that the strength and power of this muscle group depend on, among others, the angle of the knee joints [25]. Referring the results of this study to the mentioned data from literature [7], one can see that the starting position in the FS subjects was closer to that which is optimal.

The possible influence of somatic build on the effectiveness of the swim start was also taken into account, although it was indicated in previous research

conducted by the authors of this study that the starting position and movement on the block largely depended on factors other than body dimensions [21]. However, this observation was made after analysing the measurements carried out among a younger age group, with small variation in the effectiveness of the swim start. In this study, the test groups differed significantly in the time from start to reach 15 m; thus, it was decided to assess the differences in somatic build between those more and less effectively performing the start. In the course of this analysis, it was found that FS athletes were heavier than swimmers less effective in this element (SS). Nevertheless, no differences in fat levels were observed between the groups. Therefore, FS participants had a larger muscle mass, thanks to which they probably exhibited greater power of the lower limbs, as mentioned by Kavvoura et al. [26] when analysing this kind of relationship. Hence, the results of this study are partly consistent with the data found in literature, which indicate better results achieved by taller and heavier competitors over short swimming distances (50–100 m) [27]. In this type of races, the level of muscle strength is decisive for sporting success. In relation to the swimming start, factors significantly influencing the effectiveness of this element include strength and muscle power of the lower limbs [28]. Because strength depends, among others, on muscle mass, swimmers with a greater body mass are, to some extent, privileged. This, in turn, may change with age and competitive experience and therefore we may not speak of full similarity regarding the results of the earlier cited studies.

Perhaps the disproportions in the height of the hips on the block (H_{Hip}) resulted in different push-off in the FS and SS groups. In the case of FS competitors, a clear difference of 0.34 m was noted between the height of their hips at the time of the start signal and at the time of loss of contact with the block ($H_{\text{HipPushoff}}$). For SS swimmers, the difference was, on average, 3 times smaller and amounted to 0.11 m. Differences in the manner of push-off between the FS and SS groups confirm the values of push-off angle recorded in these groups. It was noted that swimmers from the FS group directed their push-off more flatly (lower A_{Pushoff} values). At the same time, FS obtained higher values for the angle in the hip joints (more straightened silhouette) at the time of loss of contact with the block ($A_{\text{HipPushoff}}$ in FS and SS: ca. 164° and 150° , respectively). Most likely, faster athletes directed their push-off more horizontally, which caused a significant lowering of the hips during the phase on the block. In turn, SS athletes, starting the movement from a low position of the hips,

had to direct their push-off also partially upwards; otherwise, further lowering of the hips would probably lead to a significant reduction in flight length.

The undesirable effects of a more vertical push-off among the SS competitors could also be seen in the later chronological stages of the start – the flight and underwater parts. As already mentioned, in this paper, significant differences in favour of the FS group regarding the values of horizontal flight velocity were noted (this disproportion was close to 0.5 m/s). This observation should be emphasized because, according to Tor et al. [16], this indicator is one of the best predictors of swim start. First of all, on its basis, the quality of push-off from the block may be assessed. At the same time, with proper body submersion and maintaining a streamline silhouette under water, the high speed obtained during the push-off can be maintained further in the start. This is probably why in this study, the differences in horizontal velocity in subsequent start phases decreased (the differences were significant for v_{Sub} and v_{Glide} , and nonsignificant for v_{uus}), but did not disappear completely. This means that the position on the block is an extremely important factor affecting the horizontal velocity in subsequent parts of the start, which also translates directly into the time to reach the 15-m mark.

Despite the different push-offs in the FS and SS groups, no significant technical differences were noted later in the flight phase. In particular, the above-water angle of attack ($A_{AttackAbove}$) and the angle of the hip joint (A_{HipSub}) at the time of the fingers' contact with water reached similar values in both groups. It is difficult to unequivocally assess whether the angle of attack values recorded in this study were optimal. It is also problematic to compare them with the available literature because in previous publications, the variables corresponding to $A_{AttackAbove}$ were determined with the consideration of the location of the centre of mass rather than the hip joints [6].

The authors of publications in the area of swim starts emphasize that during submersion, competitors are exposed to high-value drag forces [11]. This is due to the fact that frontal resistance increases with the square of movement velocity. That is why it is important to assume a silhouette that favours laminar flow of liquid around the athlete in the following phase – submersion. It should be mentioned that in these tests, a higher value of horizontal velocity was noted during submersion than during flight. This is probably the effect of changing the attack angle. The analysis of the results proves that during submersion, competitors from both groups changed their body position rela-

tive to the water surface. Perhaps the buoyancy force, which begins to affect swimmers as soon as they are submerged under water, also influences the increase in horizontal velocity. It cannot be excluded that other forces occurring during movement in water are also favourable for the described effect. Owing to its complexity, the issue of horizontal velocity changes between the flight and submersion phases requires further investigation.

Apart from the horizontal velocity during submersion and glide, no significant differences in the way of performing the underwater start phase between the FS and SS participants were noticed. Differences between the groups in the first ($A_{AttackSub1}$) and second ($A_{AttackSub2}$) underwater attack angles were small, which probably affected similar values of the maximal depth of head submersion. No differences were also found between the competitors from both groups with regard to the time (t_{Glide}) and length (d_{Glide}) of the glide or the place of beginning the underwater dolphin kicking movements (d_{UUS}). In terms of propelling movements of the lower limbs, there were no significant differences between the FS and SS swimmers, either. Both the horizontal velocity during underwater dolphin kicking movement and the duration of the first cycle (t_{UUS}) had comparable values in the 2 groups. Despite the apparently large percentage differences in the amplitude of underwater dolphin movement (18%), this indicator also did not provide grounds for identifying intergroup discrepancies concerning the underwater kicking. However, it should be stressed that in this study, only the first cycle of underwater dolphin movement was taken into account. Perhaps more differences between the groups could be found when extending the analysis of the start to the rest of the underwater phase up to resurfacing.

Finally, some limitations of the study should be pointed out. The research focused primarily on the analysis of the push-off, flight, submergence, and glide phases. Additionally, in the case of underwater dolphin movements, only one cycle was described. Therefore, it cannot be ruled out that the subjects from both groups differed also in terms of the time spent as well as distance covered under water. Owing to the differences in the sports level measured with freestyle results, the start time could also have been influenced by the differences in the front crawl technique used after resurfacing. Future research regarding the kick start should take into account further parts of the start, in particular, the whole time spent under water, as well as the resurfacing phase. Another limitation of this study could be associated with the choice of the sta-

tistical procedure – in particular, the fact that the categorization into the research groups was based on the difference in the mean start time (difference greater than $\pm SD$). This approach guaranteed the identification of groups that differed significantly in terms of the effectiveness of the start of the swimming performance. At the same time, such an approach caused the inclusion of low numbers of individuals in each group. Therefore, some intergroup differences could not be noticed, and there could be outliers among the members of both cohorts.

Conclusions

The results imply, among others, that kinematic indicators may be distinguished during each part of the start. In their level, there are clear differences between competitors achieving shorter and longer swimming start times. The described disproportions were noted for the initial position on the block, the manner of push-off, as well as flight velocity, submersion, and streamlining.

It was also noticed that the starting position on the block significantly influenced the way the push-off was performed and, consequently, the course of movement during further parts of the swimming start. A high position of the hips and proper knee joint flexion during the initial phase of the start allow the push-off to be performed in the desired horizontal direction. In turn, a low position is not conducive to achieving high horizontal flight velocity. In addition, directing the push-off in an upward direction increases flight time, making it easier for competitors with a lower sports level to assume the correct immersion angle and streamlined position. Swimmers with a shorter start time, mainly performing the push-off in a horizontal position, achieve a shorter flight time, but this does not negatively affect the manner of submersion – the angle of water entry and quality of streamlined position. Moreover, only competitors with a sufficiently high sports level are able to achieve a shorter swim start time.

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Conflict of interest

The authors state no conflict of interest.

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