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Comparing Swimming Starts of Flat and Deep Trajectory Underwater Movements Performed by Adolescent Male Swimmers

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Abstract

Purpose

Biomechanical analyses of the swimming start performed by the best swimmers indicates the occurrence of a few effective start types. This issue has only been described to a small degree among adolescent swimmers. The objective is to determine kinematic differences in various parts of the swimming start to the front crawl among adolescent swimmers performing a start with flat (FT) or deep underwater trajectory (DT).

Methods

The study comprised 32 male swimmers aged 16-19 (average World Aquatics score=556±88 points). The trials were recorded using two cameras (above- and underwater). A kinematic analysis of the time from start to attain 5m was performed.

Results

The maximum submersion depth was 0.94±0.09 m (FT) and 1.21±0.11m (DT). Between-group differences were observed for FT and DT, respectively, in: attack angle at the submersion (38.37±6.85° and 44.90±6.08°), the distance of maximum submersion depth (5.24±0.36m and 5.58±0.50m) and underwater angles of attack during submersion (angle of the shoulders at the of submersion: 29.40±3.90° and 34.30±4.14°, angle of the hips at the submersion: 21.70±4.52° and 26.49±5.05°).

Conclusions

It was found that swimmers can successfully use different start variants. The underwater trajectory is primarily influenced by the body position at the moment the fingers contact with the water and during submersion, and not only by the manner of performing the push-off. The authors conclude that the characteristics of the start should not be based on one variable or its selected start phase - the description of the technique should comprise a set of kinematic indices from its different parts.

Keywords: sport, biomechanics, swimming, youth, kinematic analysis

Introduction

Due to the complex structure of a swimming race, its biomechanical analysis is performed in smaller sections. It is most often divided into zones: the start, turn, full-stroke swimming (also called ‘clean swimming’) and the finish [5]. It is assumed that the swimming start lasts from the starting signal up until the swimmers completes the first 15 m of the race [2]. In 50- and 100-m swim races, this phase covers 30 and 15% of the total distance, respectively. It should therefore come as no surprise that, according to many authors, the swimming start plays an important role in a competitor’s final success [7, 17, 24].

The start is typically divided into the following phases: on the block, flight, underwater (including submersion, glide and underwater undulatory swimming) and full-style swimming up to 15 m [22, 24]. Due to the complexity of the start and the need to capture the smallest details, analysis of the swimming start is often limited to its initial parts, i.e. to the first 5 m of the race [4, 18]. In such a case, analysis covers the fragment from the starting signal to the first part of the underwater phase. The best competitors take about 1.5 s to complete these phases, and each of the above-mentioned fragments of the start differs in terms of the initial environmental conditions [14]. For example, during the block phase, the competitor should effectively use muscle strength to perform the push-off. In the flight phase, the swimmer’s task is to adopt an optimal position relative to the water surface. From the moment of submersion, the movement takes place in interaction with the water, which requires the swimmer to use the ability to minimise resistance (adopting a so-called ‘streamlined silhouette’) and effectively propel the body using underwater undulatory movements. Very often, the push-off phases are described separately, without looking for relationships between the course of movement in subsequent fragments. However, as van Dijk et al. [17] point out, the movement performed in one phase influences the initial conditions for the execution of the following one. For this reason, some authors look for such correlations - e.g. between the way of performing the push-off and submersion [3]. However, so far, no research has been undertaken on, among others, the way of performing the push-off from the starting block, submersion and the indices describing the underwater part of the start.

Correct execution of a sequence of movements in a swimming start is a difficult task. For this reason, the start should be perfected from the earliest stages of a competitive career. It should also be emphasized that even among the best swimmers, different variants of its execution can be distinguished [15]. This may result from differences in, among others, somatic build, mechanical power of the lower limbs or efficiency of underwater undulatory swimming [1, 13, 16]. The above-mentioned circumstances justify undertaking research on swim starts among adolescent athletes, who differ from adults in terms of, among others, somatic build. Importantly, current technological progress also serves this purpose. The popularisation of cameras recording images with high frequencies and resolution allows to conduct reliable and accurate research on the start, not only among top-level competitors, but also among younger ones aspiring to such a title.

The aim of the study was to determine differences in the above-water phase of the front crawl swimming start among adolescent swimmers performing a start with a deep or flat movement trajectory. An additional objective was to determine whether there are differences between the studied groups in the time from start to attain 5 m.

Methods:

The study was conducted in a 25-meter swimming pool equipped with Omega OSB11 starting blocks. The group of subjects comprised 32 adolescent male swimmers (average age 16.98 ± 0.90 years, body height 180.89 ± 5.82 cm, body mass 72.91 ± 8.09 kg) training competitively in swimming. The average weekly training volume of the subjects was 20 hours in the water and 6 on land. The sports level of the participants, measured by the result of the 100-m freestyle converted into World Aquatics points, was 556 ± 88. According to the classification proposed by Ruiz-Navarro et al. [10], the group of subjects comprised 30 competitors at sports level 4, and two representing level 5. The participants and their legal guardians (in the case of minors) were informed about the course of the study. The study was also approved by the Bioethics Committee at the Regional Medical Chamber (approval No. 3/KBL/OIL/2018).

Before beginning measurements, characteristic anatomical points were marked on the subjects' bodies with a waterproof marker:

- on the outer and inner sides, the centres of the ankle joints;
- on the outer side, the centre of the left hip and shoulder joints.

All marked points were visible from a distance of at least 10 metres. The marking of points on the body of each subject was always done by the same person with appropriate anatomical knowledge.

The subjects then performed a land-based warm-up according to the RAMP protocol [9]. After a water-based warm-up supervised by the subjects' coaches (volume 800-1,200 m, mostly at low- and short high-intensity intervals), there was a 10-minute rest during which the participants were familiarised with the testing procedure. After this, in accordance with World Aquatics swimming rules, the subjects performed three front crawl starts. The participants were given the goal of achieving the shortest possible time to reach 15 m (recording and analysis were limited to the 5-m section from the starting wall). To ensure full recovery of the subjects, each of them were given approximately 5 min for passive rest between repetitions.

The methodology designed in 2014 by ~~...~~ L. Nosiadek [8] was applied for the video recording of the swimming starts, including above- and underwater movements (window). This is based on two types of time-synchronised cameras: the Casio Exilim EX-FH25 (Casio, Japan) and the SONY DSC-RX100M3 (Sony, Japan), enabling the recording of images at a frequency of 120 frames/s. This methodology was further used in a number of publications [20-22]. Both cameras were placed on stable tripods, perpendicular to the main direction of the subjects' movement, at a distance of approx. 6 m from the lane along which the subjects moved. The Sony device was placed in a way that enabled the recording of the above-water part of the movement - from the starting signal to complete submersion of the subject. The Casio camera was positioned behind the underwater window, allowing the movement to be recorded from finger immersion until the centre of the head passed a previously marked line 5 m from the starting wall.

The cameras were synchronised using the SwimStartSynchro system (Opti.Eng., Poland), developed for use in previous research [21, 22]. The device simultaneously emitted two light signals visible in the lens of both cameras and an audible start signal.

Of the three attempts performed by each swimmer, the start in which the subject achieved the shortest time to attain 5 m was subjected to further analysis. The SkillSpector program (version 1.3.2, Video4coach, Denmark) was used to determine the values of kinematic indices. For both under- and above-water movements, a six-point model was created for the purposes of the study. The description of the determined variables is included in Table 1. Examples of determining the angular values for selected fragments of the start are presented in Figures 1-3. The remaining angular variables, not included in the figures, were determined in a manner analogous to those presented. For the hip joint, it was assumed that the value of 180° corresponds to the situation in which the hip joint was in a position corresponding to that anatomically neutral (the trunk section and lower limbs constitute a straight line, as in standing). Values below 180° represent a situation in which the hip joint was in flexion (as in Figure 2), while above this value, the hip joint was in extension.

Fig.1 Way of determining push-off (APushOff - black) and hip angle during the push off (AHipPushOff - red).

Fig.2 Way of determining attack (AAttackSub - red) and first hip angle during submersion (AHipSub1 - black).

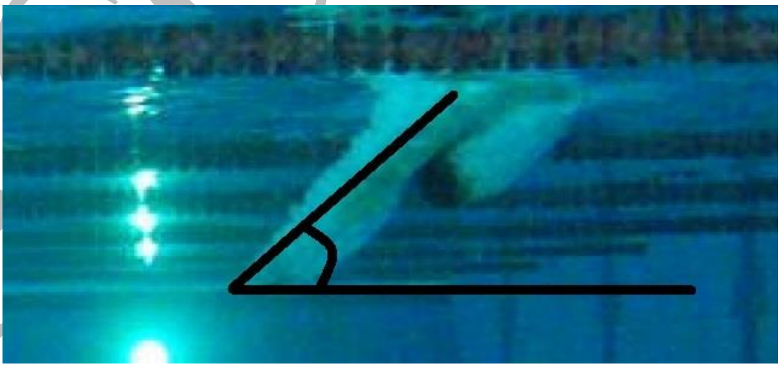

Fig.3 Way of determining underwater attack angle during shoulder joint submersion (AAttackUnd1).

Tab.1 Description of variables

Variable	Unit	Description
t_5	s	Time from starting signal until middle of head reaches distance of 5 m
$A_{PushOff}$	deg.	Push-off angle - angle between horizontal line and biomechanical axis of front lower limb (hip and ankle joint) at time of loss of contact with block (apex - ankle joint)
$A_{HipPushOff}$	deg.	Hip angle at push-off - angle in hip joint of rear lower limb at time of completing push-off (segments: shoulder joint - hip joint and hip joint - upper ankle joint, apex: hip joint)
$A_{AttackSub}$	deg.	Attack angle during submersion - angle between line of water surface and upper limb at time of finger contact with water (apex - finger)
$A_{HipSub1}$	deg.	First hip angle during submersion - angle in hip joint of front lower limb at time of finger contact with water (segments: shoulder joint - hip joint and hip joint - upper ankle joint, apex: hip joint)
$A_{HipSub2}$	deg.	Second hip angle during submersion - angle in hip joint of front lower limb at time of head contact with water (segments: shoulder joint - hip joint and hip joint - upper ankle joint, apex: hip joint)
$A_{HipSub3}$	deg.	Third hip angle during submersion - angle in hip joint of front lower limb at time of shoulder joint contact with water (segments: shoulder joint - hip joint and hip joint - upper ankle joint, apex: hip joint)
H_{Max}	m	Maximal depth of centre of head submersion with respect to water surface
D_{Max}	m	Horizontal distance from starting wall to place of achieving maximal depth of centre of head submersion with respect to water surface
$A_{AttackUnd1}$	deg.	First underwater attack angle - angle between level and upper limb at time of shoulder joint submersion (apex - shoulder joint)
$A_{AttackUnd2}$	deg.	Second underwater attack angle - angle between level and upper limb at time of hip joint submersion (apex - shoulder joint)
$A_{AttackUnd3}$	deg.	Third underwater attack angle - angle between level and upper limb at time of toe submersion (apex - shoulder joint)

Calibration of the recordings (assignment of coordinates (x, y) to points marked on the subjects' bodies) was carried out using a square frame with dimensions of 1.02 x 1.02 m. Data from graphs created via the SkillSpector program were exported to MS Excel (version 365, Microsoft Corporation, USA).

Statistical analysis

Statistical procedures were performed in the Statistica program (version 13, StatSoft, Poland). Thirty-two subjects were divided into two, 16-person groups: FT (‘Flat Trajectory’) and DT (‘Deep Trajectory’). The first group included swimmers achieving the 16 lowest values for the H_{Max} index, while the remaining participants were assigned to the DT group. For both distinguished groups, means, standard deviations as well as medians and quartiles were calculated. Due to the lack of fulfilment of the criterion of normal distribution (Shapiro-Wilk test) and homogeneity of variance (Levene test), ~~T~~the non-parametric Mann-Whitney *U* test was applied to assess between-group differences, assuming a significance level of $p<0.05$. The Cohen's *d* effect size was also calculated, assuming a small, medium, large and very large effect for values of r $0.2 \leq r < 0.5$, $0.5 \leq r < 0.8$ and $0.8 \leq r$, respectively [23].

~~Insert Figure 1 here~~

~~Insert Figure 2 here~~

~~Insert Figure 3 here~~

Results:

The means and standard deviations recorded for the groups are presented in Table 2. The results of the Mann-Whitney *U* test regarding differences are also included.

Tab.1 Descriptive characteristics of swimmers for flat (FT) and deep start (DT) underwater trajectory

Variable	Mean ± SD		*p*-value	Effect size
	FT	DT		
t_5 [s]	1.71 ± 0.06	1.65 ± 0.16	0.17	0.49
$A_{AttackPushOff}$ [deg]	30.07 ± 5.33	30.14 ± 8.15	0.81	0.02
$A_{HipPushOff}$ [deg]	147.35 ± 3.96	152.10 ± 9.97	0.34	0.63
$A_{AttackSub}$ [deg]	38.37 ± 6.85	44.90 ± 6.08	0.01	1.01
$A_{HipSub1}$ [deg]	177.14 ± 16.91	169.81 ± 16.60	0.31	0.44
$A_{HipSub2}$ [deg]	176.85 ± 14.75	173.07 ± 13.26	0.36	0.27
$A_{HipSub3}$ [deg]	176.56 ± 13.95	176.34 ± 13.10	0.69	0.02
H_{Max} [m]	0.94 ± 0.09	1.21 ± 0.11	0.01	2.76
D_{Max}[m]	5.24 ± 0.36	5.58 ± 0.50	0.04	0.77
$A_{AttackUnd1}$ [deg]	29.40 ± 3.90	34.30 ± 4.14	0.01	1.21
$A_{AttackUnd2}$ [deg]	21.70 ± 4.52	26.49 ± 5.05	0.02	1.00
$A_{AttakUnd3}$ [deg]	11.10 ± 5.06	15.57 ± 7.83	0.06	0.68

The data presented in Table 2 do not indicate any significant differences between groups for the time to achieve 5 m. The disproportion between subjects from the FT and DT groups in the t_5 index was 0.06 s in favour of the DT group with small effect size ($d = 0.49$). The groups differed primarily in terms of the indices describing the underwater part of the movement. The subjects from the FT group achieved lower values for H_{Max} ($d = 2.76$) and D_{Max}, although in the case of the second variable the effect size was medium. The start performed by these swimmers was also characterised by lower values of underwater attack angles: $A_{AttackUnd1}$ and $A_{AttackUnd2}$. Cohen's d effect sizes for these variables were large.

With reference to the above-water indices, $A_{AttackSub}$ assumed higher values in the DT group. This was the only variable out of 6 describing above-water movements for which significant differences were revealed between the groups and the effect size was large.

Significantly different statistical characteristics for each group of variables are illustrated in Figures 4-8.

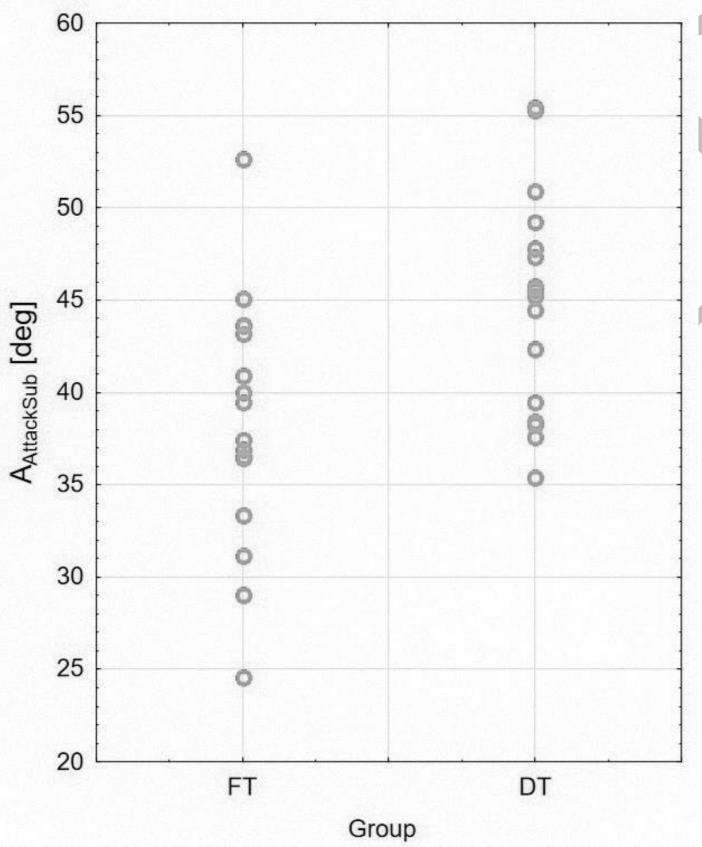

Fig.4 Results summary of AAttackSub angle values in Flat (FT) and Deep Trajectory (DT) groups

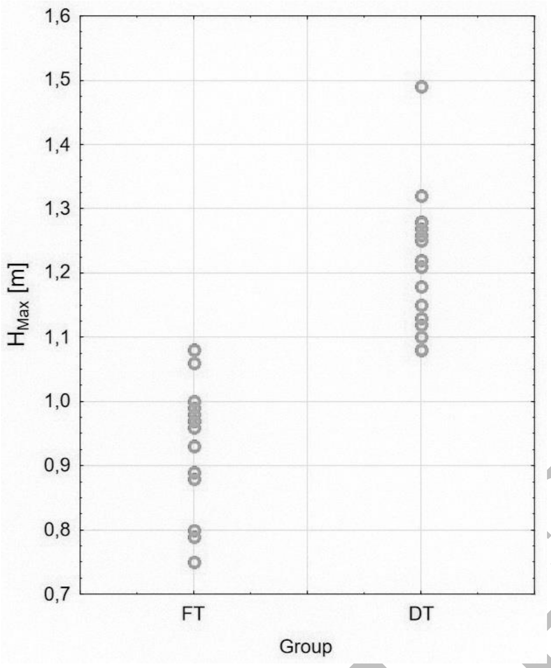

Fig.5 Results summary of HMax values in Flat (FT) and Deep Trajectory (DT) groups

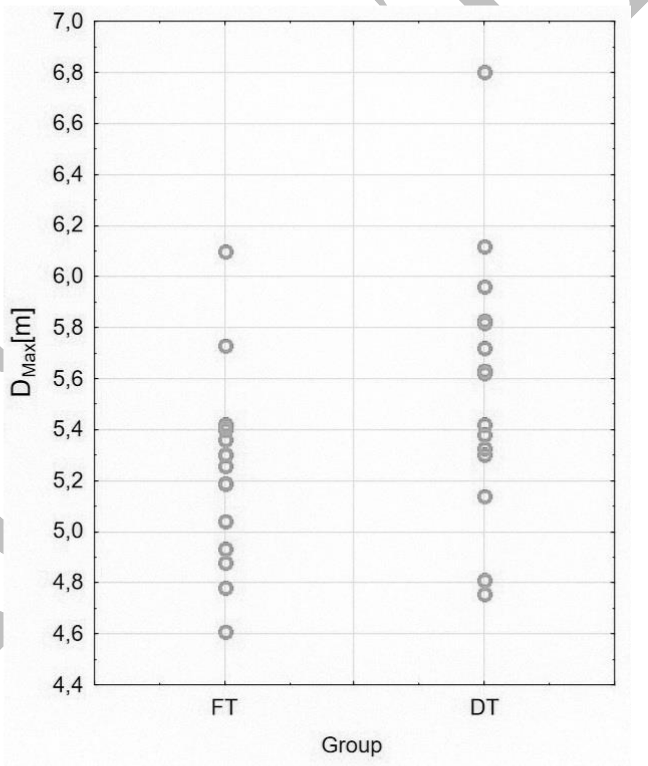

Fig.6 Results summary of DMax values in Flat (FT) and Deep Trajectory (DT) groups

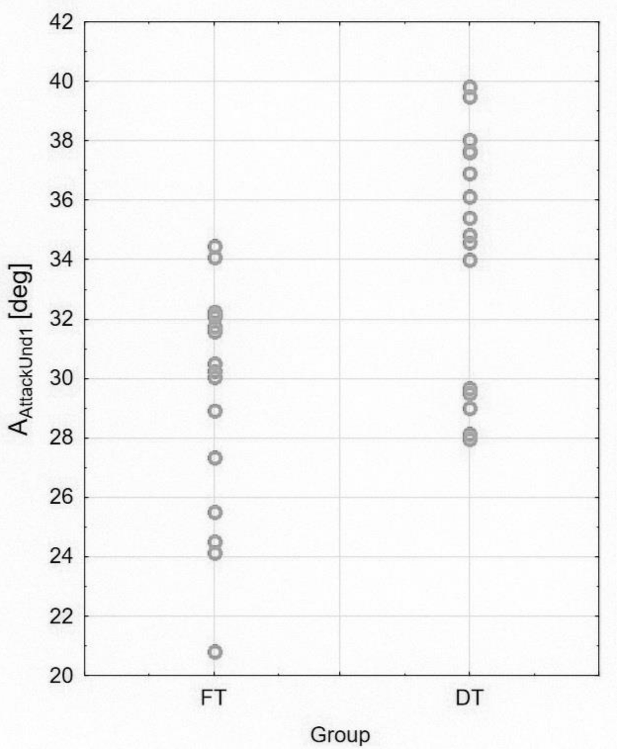

Fig.7 Results summary of AAttackUnd1 angle values in Flat (FT) and Deep Trajectory (DT) groups

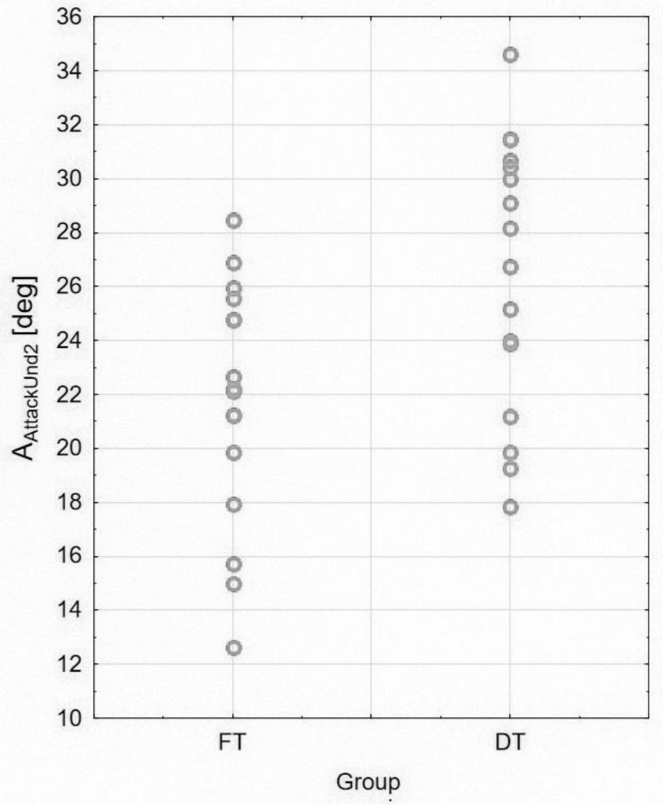

Fig.8 Results summary of AAttackUnd2 angle values in Flat (FT) and Deep Trajectory (DT) groups

Discussion:

The aim of the present study was to find differences in the swim start between swimmers moving with a deep or flat underwater trajectory. It was noted that the swimmers primarily differ in terms of indices describing movement after submersion. It was also observed that swimmers from the DT group achieved higher values for attack angle at the moment the fingers came to contact with the water. The groups did not differ significantly with regard to the time to attaining 5 m.

The subject of previous research has also been a description of the Kick Start technique. This type of race start is performed from a starting block equipped with an adjustable block (‘slanted foot rest’), on which the hind limb is placed. Currently, the Kick Start is more often used by swimmers in competitions than older techniques (Grab Start and Track Start) in which the foot rest is not used [16]. In numerous studies [11, 12, 16], it has been indicated that there are significant differences in the course of movement between the Kick Start and other start types. This means that relating the results of this study to past work is limited. It is not possible to compare clearly distinguished start variants to the ones used in Grab and Track Start.

In the current study, there was no evidence that the subjects from the FT and DT groups differed significantly in terms of time to the 5-m mark. This gives grounds to assume that the subjects from both groups performed the start in a similarly optimal way, including its underwater part. As reported by Tor et al. [15], swimmers moving with an exceptionally flat underwater trajectory (maximum submersion values of 0.0-0.7 m) achieve a longer start time. This results from the fact that the wave resistance acting on the swimmer is significant in the case of flat submersion [19]. On the other hand, a very deep underwater movement trajectory (over 1.5 m) extends the distance that a swimmer covers vertically, which may also negatively affect the start time.

As indicated by Tor et al. [14], during the start, the maximum depth of submersion in the case of world-class male swimmers is 1.05 m. In this study, the H_{Max} values for the FT and DT groups were 0.94 m and 1.21 m, respectively with large effect size. Of course, differences in the research methodology as well as the selection of groups (sports level of the subjects, somatic build) between the present and cited studies make it difficult to compare the measurement results. However, it seems that in terms of the maximum submersion depth, the subjects were within the range of optimal values for this index. At the same time, it should be emphasized that within the context of a swimming start, there is no single ‘ideal’ movement pattern. As suggested by Vantorre et al. [18], there may be several equally effective ways of performing the start, depending on the physiological and anthropometric characteristics of a swimmer. Based on the results of the current study, it may be indicated that this complexity of the issue does not only apply to the elite level, but also to adolescent swimmers.

In this study, it is shown that high H_{Max} values are also accompanied by high angle values at the moment of submersion ($A_{AttackUnd1}$ and $A_{AttackUnd2}$) and D_{Max}. It seems that the angle assumed by the upper limbs with the water surface during submersion has a direct effect on the maximum depth and the distance covered underwater. Swimmers who are able to achieve high swimming speeds using underwater undulatory swimming should probably optimise their push-off technique, aiming towards high values of attack angle during submersion. This results from the fact that a greater depth reached underwater is beneficial due to lower values of wave resistance [19]. On the other hand, those who are less effective in this element should strive to achieve lower values of the attack angle. At the same time, coaches should monitor the quality of start performance among their athletes, not only in terms of above- but also underwater courses of movement. Any technical correction should take place considering the degree of mastery of the underwater undulatory swimming technique.

The FT group subjects did not significantly change hip angle values ($A_{HipSub1}$, $A_{HipSub2}$, $A_{HipSub3}$) during submersion. Of these three variables, only the first one had a small effect size. This submersion selection strategy has been described in the literature as ‘flat’ in relation to the Grab Start technique [3]. The DT swimmers proceeded in a different way - they extended their lower limbs in the hip joints during submersion (the value of the $A_{HipSub1}$ angle was lower than that of $A_{HipSub3}$). This method of execution has been called (also in relation to the Grab Start) the ‘pike start with quick deflection’ [3]. Potentially, the lack of hip extension movement among the DT group subjects could result in larger amounts of water displaced at the moment of submersion. In the literature, this is described as ‘big hole entry’ and is considered an error resulting in significantly increased resistance during submersion [16]. This allows to highlight the importance of observing body position not only during finger contact with the water and under it, but also during submersion.

The subjects from both groups differed in terms of movements performed above water – the $A_{AttackSub}$ angle reached higher values in the DT group with large effect size. Therefore, it seems that the course of underwater movements may be partially related to the position of the body in relation to the water surface not only during submersion, but also directly before it (at the moment the fingers contact the water). Due to the different method of determining attack angle during submersion, the values from the authors’ research cannot be related to the data from literature [6, 11, 14, 15]. However, it can be stated that high values of H_{Max} are accompanied by both high values of attack angles during submersion ($A_{AttackUnd1}$ and $A_{AttackUnd2}$)

and at the moment the fingers come to contact with the water ($A_{AttackSub}$). The assessment of the body position when the fingers contact the water can thus be the basis for determining the potential trajectory of underwater movements. This finding is especially valuable from the point of view of coaching practice, in which the use of underwater movement analysis using waterproof cameras is limited.

In this study, the groups were not observed to differ in terms of the way the push-off was performed. Both $A_{AttackPushOff}$ and $A_{HipPushOff}$ demonstrated similar values in both groups, had similar values, although in the case of the second variable the effect size was medium. This fact seems somewhat surprising, because in previous literature, there are assumptions regarding possible relationships between the way the push-off was carried out and the course of movement during the underwater phase [3, 17]. So far, it has been proven that the way the push-off is performed affects the swimmer's behaviour during the flight and his/her position at the moment the fingers contact the water [16]. For this reason, there were also assumptions regarding a possible relationship between the way the push-off was performed and the further parts of the start, e.g. the course of underwater movements [17]. However, in this study, the FT and DT groups were not observed to differ in terms of the way the push-off was conducted. $A_{AttackPushOff}$ and $A_{HipPushOff}$ exhibited similar values in both groups. Therefore, as the results of this study indicate, the influence on the further part of the push-off (submersion, underwater trajectory) is rather exerted by other, previously described push-off phases, and not by the manner of its performance.

There are a few limitations of the present study. First of all, the start efficiency was assessed based on the time to attain 5 m, which is a method known from the literature in this field [4, 11], but not as frequently used as recording 10- or 15-m distances. If a longer section had been selected, the number of potential variables for analysis would have been significantly increased [11]. The course of movement in the Kick Start may differ depending on the block adjustment. This has been described more detailedly in literature on this subject [6]. In accordance with the adopted objective of the study, it was decided to characterise the start with the block set to the position preferred by the swimmers. For this reason, the number of designated variables was limited to characterising two variants of the technique. Due to this, several kinematic indices commonly used in swimming start trials (e.g. horizontal flight speed or flight length) were not determined [16].

Conclusions:

This study allows to draw the following conclusions:

1. There are several differences in the course of movement during a swimming start depending on underwater movement trajectory. They mainly concern the position of the body at the end of the flight phase and during submersion.
2. A set of kinematic indices should be taken into account in the description of the technique for starting a swimming race. For this reason, the characteristics of the start should not be based on one variable or a selected start phase.
3. The course of underwater movement is influenced by the position of the body at the moment the fingers come to contact with the water and during submersion, and not by the way of performing the push-off.
4. In the case of adolescent competitors, there are several effective ways of performing the start. For this reason, swimmers should try to perform different start variants, seeking an optimal technique.

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