

Biomechanical Analysis of the Swim-Start: A Review

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Abstract

This review updates the swim-start state of the art from a biomechanical standpoint. We review the contribution of the swim-start to overall swimming performance, the effects of various swim-start strategies, and skill effects across the range of swim-start strategies identified in the literature. The main objective is to determine the techniques to focus on in swimming training in the contemporary context of the sport. The phases leading to key temporal events of the swim-start, like water entry, require adaptations to the swimmer's chosen technique over the course of a performance; we thus define the swim-start as the moment when preparation for take-off begins to the moment when the swimming pattern begins. A secondary objective is to determine the role of adaptive variability as it emerges during the swim-start. Variability is contextualized as having a functional role and operating across multiple levels of analysis: inter-subject (expert versus non-expert), inter-trial or intra-subject (through repetitions of the same movement), and inter-preference (preferred versus non-preferred technique). Regarding skill effects, we assume that swim-start expertise is distinct from swim stroke expertise. Highly skilled swim-starts are distinguished in terms of several factors: reaction time from the start signal to the impulse on the block, including the control and regulation of foot force and foot orientation during take-off; appropriate amount of glide time before leg kicking commences; effective transition from leg kicking to break-out of full swimming with arm stroking; overall maximal leg and arm propulsion and minimal water resistance; and minimized energy expenditure through streamlined body position. Swimmers who are less expert at the swim-start spend more time in this phase and would benefit from training designed to reduce: (i) the time between reaction to the start signal and impulse on the block, and (ii) the time in transition (i.e., between gliding and leg kicking, and between leg-kicking and full swimming).

Key words: Biomechanics, expertise, performance, techniques, variability.

Literature search methodology

MEDLINE and ScienceDirect were searched for primary sources using six keywords: expertise, performance, technique, variability, swimming and start. These were pooled (via Boolean operation "OR") and combined (via Boolean operation "AND") with similarly pooled keywords related to swimming biomechanics. The proceedings of international congresses on biomechanics and swimming databases were also searched, from their earliest available records up to November 2012. Relevant articles were sought on Google Scholar, and the cited articles and reference lists of all included studies were carefully scrutinized. The articles analyzing swim-starts were restricted to those written in English. Full publications and abstracts

were screened, and all relevant studies were retrieved. A standardized form was used to select the studies eligible for inclusion. Ultimately, 45 references and eight books were selected from the previously selected articles and books from the MEDLINE, ScienceDirect and Google Scholar searches; an additional 17 references were retrieved from the proceedings of sport sciences congresses. Disagreement was resolved by achieving consensus among the authors, who took into account the size of the population studied and the swimming skill level for inclusion.

The start in a swimming event

Recently, interest in swimming-specific research has begun to accelerate (Pelayo and Alberty, 2011). Indeed, Vilas-Boas (2010) noted that swimming is now one of the most investigated physical activities, based on the number of published research articles and the number of countries represented at international meetings. Part of this rise in interest may be related to the ongoing modifications in the swimming rules, driven by changes in swimming techniques and technologies, all of which have inspired new research directions. This includes the swim-start (SW 7 of the FINA rules), which has undergone several changes from a regulatory point of view. For example, on January 1, 2010, a new kick-start block was authorized, with a raised rear section to assist the track start technique (Omega OSB11). Competition analysis has provided information on the start time (to 15-m), turn times (7.5-m into and out of the wall), and finish time (5-m into the wall), as well as the stroke length, stroke rate and velocity, for each 25-m section of free swimming (Mason and Cossor, 2000). Moreover, the start time has been quantitatively evaluated in relation to the swimming, turn and finish times in order to assess its contribution to overall performance (Arellano et al., 1996; Costill et al., 1992; Lyttle and Benjanuvatra, 2005; Mills and Gehlsen, 1996; Vilas Boas et al., 2003). The results indicate that the start time to 15-m can account for anywhere between 0.8% and 26.1% of the total race time, depending on the event (Lyttle and Benjanuvatra, 2005) (i.e., the latter percentage reflecting the percentage in sprint events). Moreover, contrary to the block starts in long-distance events, in which the athlete has to accelerate from zero to full running speed, dive swim-starts enable swimmers to enter into the water faster than average swimming speed, which further underlines the great importance of the swim-start in sprints. Effective diving techniques enable swimmers to exploit the speed generated during the dive and are in line with the principle of efficiency that drives every

phase of the competitive event (Kilduff et al., 2011; Lyttle and Blanksby, 2011).

Analysis of swimming start kinematics

Methodology

The studies on the swim-start have analyzed several parameters. Kinematic analyses of swim-start behavior and performance, for example, have usually compartmentalized the start into distinct phases, such as block time, flight time and underwater time (Arellano et al., 1996; Cossor and Mason, 2001; Vilas-Boas et al., 2003). More recent studies have assumed that the start actually begins with the reaction to the start signal and the push from the block (Benjanuvattra et al., 2007; Bishop et al., 2009; De la Fuentes et al., 2003; Slawson et al., 2013). These trials were recorded at 50 Hz with a digital video camera placed perpendicularly to the direction of movement. Vantorre et al. (2010a) used both fixed cameras (placed at 5-m and 15-m) to determine phase limits and underwater mobile cameras on a trolley to analyze qualitative variables and stroking parameters like stroke length or frequency. The forces applied during the push from the starting block were analyzed via custom-built, instrumented starting blocks. Force curves measured the impulse in the horizontal and vertical axes (in $\text{N}\cdot\text{kg}^{-1}$) (Benjanuvattra et al., 2007; Blanksby et al., 2002; Lee et al., 2001; Slawson et al., 2013; Vantorre et al., 2010b, 2010c; Vilas-Boas et al., 2003; West et al., 2011). The kinetic analysis of the block phase quantified the impulse and described its direction relative to the direction of movement (Benjanuvattra et al., 2007; Blanksby et al., 2002; Lee et al., 2001; Slawson et al., 2013; Vantorre et al., 2010b, 2010c; Vilas-Boas et al., 2003).

Block Phase

Several studies of swim-start phase kinetics, particularly the reaction time on the starting block and the flight and entry phases, have drawn parallels with the start in track and field (Ayalon et al., 1975; De la Fuentes et al., 2003; Issurin and Verbitsky, 2003; Krüger et al. 2003; Miller et al., 2003; Vilas-Boas et al., 2003; Zatsiorsky et al., 1979). However, from a biomechanical point of view, these starts differ in many ways. Moreover, among swimmers, the starts also differ according to specialty. Sprint swimmers need to rotate backwards to bring themselves upright, whereas longer-distance swimmers need to focus on the distance covered while in the air and the body orientation at water entry. Here, breaking down the swim-start is not only a spatial matter, but also a matter of motor changes during the overall start movement. From this perspective, studies on the block phase (Benjanuvattra et al., 2007; Vantorre et al., 2010a) have shown that two distinct actions must be optimized: a rapid reaction to the start signal and high impulse generated over the starting block. The studies on the block phase have usually been kinetic analyses focused on the force applied to the block or on training programs designed to improve the start (Bishop et al., 2009; Breed and Young, 2003; De la Fuentes et al., 2003; Lee et al., 2001). The reaction time needs to be as brief as possible, while the movement phases on the block

need to last long enough to maximize the swimmer's impulse to achieve high horizontal velocity (Breed and Young, 2003). In other words, a compromise needs to be struck between spending too much time on the block to create more force and spending too little time on the block to minimize the time deficit and avoid being "left at the start" (Lyttle et al., 1999).

Flight and entry phases

Breaking down a swim-start into its component parts can be challenging as the phases are not always clear cut. Maglischo (2003) defined water entry as the moment when the hand enters the water. This definition is widely used to determine the end of the flight phase, during which swimmers need to jump as far as possible and travel the maximum distance at the high velocity developed during the block phase (Hubert et al., 2006; Sanders and Byatt-Smith, 2001). Ruschel et al. (2007) reported that flight duration is not correlated with start time but that flight distance is one of the variables that determine starting performance ($r = -0.482$). Maglischo (2003) noted that the block phase strongly influences the flight phase by imposing a compromise between the pike and flat styles for the aerial trajectory (Maglischo, 2003). The pike start has a longer start time, greater take-off and entry angles, and a shorter distance to head entry into the water than the flat start (Counsilman et al., 1988). Wilson and Marino (1983) showed a shorter 10-m start time, greater entry angle, shorter distance to water entry, and greater hip angle at entry for the pike start than for the flat start. However, after five training sessions, Kirner et al. (1989) reported that the grab start/flat entry showed a shorter 8-m start time and a smaller entry angle than the grab start/pike entry. Thus, the flat start aims for a quick entry into the water using a flatter body position and earlier stroking. The pike start creates a smaller hole for water entry (i.e., angle of entry more vertical to the water surface) with higher velocity due to the influence of gravity, but it requires a horizontal (body position from the surface) then vertical (until break out the water surface) underwater recovery, which causes higher resistance. Vantorre et al. (2010a) studied swim-starts and found that strategies differ even among elite swimmers. These authors observed that the swim-start profiles included differences in how the limbs were used to achieve specific trajectory styles, such as the Volkov start, with the arms back during the leg impulse, or the flight style start, with the arms directly in front of the head (Vantorre et al., 2010a). However, the swimmer's task during the flight phase is not merely to go as far as possible. Mclean et al. (2000) and Vantorre et al. (2010a; 2010b) showed that swimmers must also generate enough angular momentum to make a clean entry into the water, which means that they need sufficient time to rotate while in flight in order to enter the water through a small hole. Arm movements influence angular momentum and during the forward rotations of the swim-start, a forward arm swing decreases rotation and, inversely, backward rotations increase body rotation (Bartlett, 2007a). Therefore, to manage the angular momentum generated during the block phase, swimmers can make a flat start (less angular

momentum and a flat trajectory) or a Volkov start with a backward arm swing (more angular momentum and a pike trajectory) (Seifert et al., 2010; Vantorre et al., 2010d). Swimmers enter the water at an angle maintained during the descent phase of flight.

Glide phase

After the aerial phases (block, flight and entry phases), swimmers have to manage the transition from air to water (Maglischo, 2003), with the glide beginning when the head enters the water and ending when the head breaks out (Counsilman et al., 1988). After water entry, the swimmer remains in a streamlined position for as long as possible to maintain the velocity acquired in previous phases and progressively assumes a horizontal position: this is the glide phase. Cossor and Mason (2001) and Sanders (2004) indicated that finish performances are highly correlated with the swim-start time spent underwater during the glide phase. However, few studies have actually measured this, with most focusing on the aerial phase. De Jesus et al. (2011) showed the importance of the compromise between underwater velocity and backstroke start performance. Guimaraes and Hay (1985) and Hay (1988) concluded that glide time is more important to the start phase than either block time or flight time (explaining 95% of the variance of the starting time for $r = 0.97$). Maintaining a streamlined body position after water entry is vital to slowing the loss of velocity. Clear evidence of this is shown when swimmers are being towed, as they produce greater hydrodynamic resistance in the supine position than in the prone position (Clarys and Jiskoot, 1975; Counsilman, 1955). These observations indicate that body shape, rather than surface area, is the decisive component when determining the proportion of the total resistance. For example, placing one hand on top of the other, as opposed to positioning the hands in shoulder alignment, caused a 7% decrease in resistance (Bulgakova and Makarenko, 1966) (Figure 1).

Given the importance of this phase for starting performance, some authors have developed methods to quan-

tify the quality of gliding with drag coefficients using computational fluid dynamics analysis (Naemi et al., 2010; Naemi and Sanders, 2008; Vilas-Boas et al., 2010). Bixler et al. (2007) validated this tool for swimming studies. The glide factor is the measure of glide efficiency that accounts for the combined effects of resistive forces and added mass. The quality of gliding is thus measured in terms of the adopted posture and the flow characteristics around the swimmer's body. The glide factor (expressed in meters) is attained when a gliding body (the swimmer) has an initial velocity of $2 \text{ m}\cdot\text{s}^{-1}$ and decelerates to $1 \text{ m}\cdot\text{s}^{-1}$ in half a second. Naemi and Sanders (2008) showed that this is linked to the swimmer's size and shape. The inertial and resistive characteristics of a streamlined body affect the glide efficiency. A study of the breaststroke start found that for the same average gliding velocity ($1.37 \pm 0.124 \text{ m}\cdot\text{s}^{-1}$) during the swim-start, the values for the first glide position before the first arm pull were significantly lower than the values for the second glide position of the underwater breaststroke stroke (Vilas-Boas et al., 2010). These findings supported those of Seifert et al. (2007), who found that breaststroke swimmers tended to spend too much time gliding while in the second glide position of the breaststroke start.

Underwater propulsion

Swimmers must manage the glide, underwater kicking and the break-out to start swim stroking (Elipot et al., 2009; 2010; Maglischo, 2003; Vantorre et al., 2010a). Thus, the swim-start is not just limited to the block and aerial phases, but continues until the swimmer re-surfaces and commences swim stroking up to the 15-m mark in all strokes except the breaststroke, according to FINA rules. Few studies have analyzed the underwater phase of the start even though it contributes considerable distance at the beginning of a race, particularly in the breaststroke (Arellano et al., 1996; Cossor and Mason, 2001; Guimaraes and Hay, 1985; Vilas-Boas et al., 2003). Cossor and Mason (2001) found a negative correlation ($r = -0.734$) between the underwater velocity and the 15-m

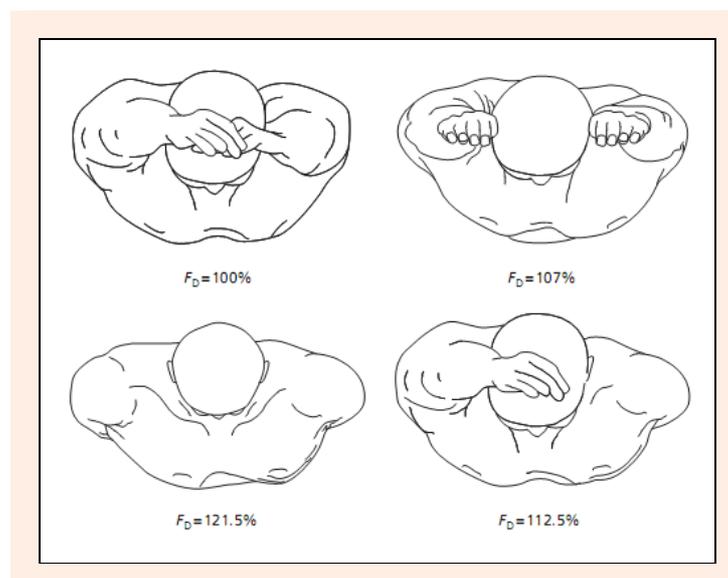


Figure 1. Impact of body shape on flow resistance when the body is pulled (proportion of resistance in relation to total resistance in gliding position corresponding to 100%) (Bulgakova and Makarenko, 1996).

start time in 100-m backstroke and 100-m breaststroke events, thereby suggesting the value of high velocity during the underwater phase to achieve high swim velocity. Some authors have underlined the importance of quantifying the underwater phase of the start (Sanders, 2002), but few have focused on doing so, or on underwater leg propulsion (Blanksby et al., 1996; Clothier et al., 2000; Elipot et al., 2010; Lyttle et al., 1998, 2000; Takeda et al., 2009). Indeed, despite a paucity of data, authors acknowledge that the underwater phase time is fundamental to achieving an effective swim-start (Sanders, 2004; Vilas-Boas et al., 2003; Vilas-Boas et al., 2000). This conviction was expressed in the study of Pereira et al. (2003), who suggested that the time between water entry and the 15-m mark is the most important variable in swim-start performance. For all strokes other than breaststroke, only the legs are used during the underwater phase. The underwater phase in breaststroke is specifically defined by the FINA rules as follows: “*after the start and after each turn, the swimmer may take one arm stroke completely back to the legs during which the swimmer may be submerged. A single butterfly kick is permitted during the first arm stroke, followed by a breaststroke kick*” (SW 7.1 FINA). This specification has led some authors to analyze the propulsive and gliding actions, and the velocity during this part of the start (Seifert et al., 2007; Vilas-Boas et al., 2010). These authors showed that both national and international swimmers often demonstrate a similar problem: a negative superposition of leg propulsion with arm recovery at the pull-out phase, which is resolved at the first swim stroke. Furthermore, these authors showed that the difficulty in achieving optimal arm-leg coordination is due to an increase in velocity that limits the scope for adaptive variability. In freestyle, swimmers generally begin stroking too early, which generates more drag than if they had continued gliding for an extended period (Sanders and Byatt-Smith, 2001). Elipot et al. (2010) also emphasized the importance of the relationship between gliding and underwater kicking to maintain the velocity acquired by the diving start. Houel et al. (2013) stated that swimmers should ideally start dolphin kicks after approximately 6-m of glide and need to be efficient, with a high rate of kicking. Motor organization during the underwater phase should be optimized in relationship to these parameters. A study of expert and non-expert swimmers described the underwater phase as including a leg kicking phase and actually counted the number of leg undulations (Vantorre et al., 2010c). This allowed the authors to distinguish gliding from leg propulsion in terms of relative duration and quantity and pointed to the

challenging transitions with regard to the respective parameters. The leg kicking phase was calculated as the time between the beginning of leg propulsion and arm propulsion: when kicking and stroking started at the same time, it was equal to 0 seconds; when the swimmer started kicking before stroking, it was >0 seconds; and when the swimmer started stroking before kicking, it was <0 seconds.

Kinematic profiling

Vantorre et al. (2010a) segmented the start into six phases (see Figure 2): (i) block phase (the time between the signal and the instant the swimmer's toes leave the block), (ii) flight phase (the time between the instant the toes leave the block and hand entry), (iii) entry phase (the time between hand entry and toe immersion), (iv) glide phase (the time between toe immersion and the beginning of the underwater propulsion of the legs), (v) leg kicking phase (the time between the beginning of leg propulsion and arm propulsion), and (vi) swimming phase (the time between the beginning of the first stroke and the arrival of the head at the 15-m mark).

The main objective of swim-start research has been to identify the most effective start technique in terms of performance. Tools like stepwise regressions can be used to analyze various parts of the start with a focus on qualitative aspects. For example, Vantorre et al. (2010a) investigated what expert swimmers do during the underwater phase up to the 15-m mark, analyzing behavioral parameters such as leg kicking, number of leg undulations, number of arm strokes, and arm coordination to 15-m. These authors assessed the time spent in each phase and attempted to determine the most effective profiles for start performances. Using these qualitative parameters, cluster analysis determined whether the expert swimmers employed the same strategies to achieve an optimal start. The profiles that emerged were in line with the two main attributes of an effective start: knowing when to stop gliding and begin leg kicking, and knowing when to begin the transition from leg undulation to full swimming.

Expertise in the swimming start

Definition

Swimming federations often define swimming levels using qualification grids. For maximal facility and standardization, performances during swimming studies are expressed as trial times and expertise can be characterized as a percentage of the world record (WR). Performances greater than or equal to 90% of WR are

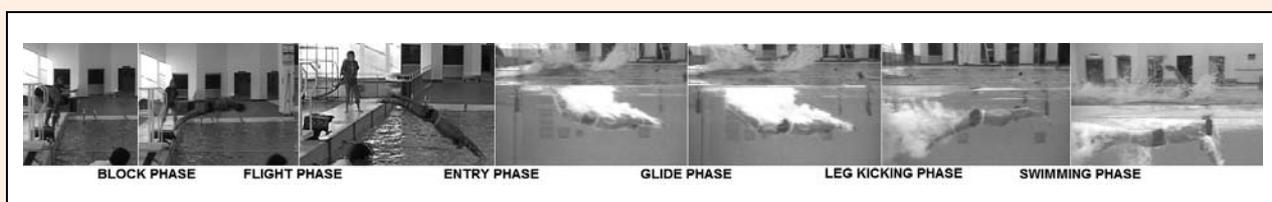


Figure 2. Start phases to 15-m (Vantorre et al., 2010a).

considered to be elite. Thus, the swimming level is usually based on chronometric performance. However, chronometric performance is an overly gross measure and may be insufficient to define expertise, especially for practical purposes. For example, high performance has been linked to the ability to start well, yet a swimmer can be an expert for the 50-m or 100-m event (sprint events) but not be within the performance range commensurate a start expert. As previously noted, the swim-start is one of several parts of an event and deserves to be considered as a distinct skill. Seifert et al. (2007) and Vantorre et al. (2010c) found that the swim-start influences coordination during the first strokes after break-out into swimming in both breaststroke and freestyle. This is due to the high velocity acquired at the start and the glide plus movements generated during the underwater propulsion period (Seifert et al., 2007; Vantorre et al., 2010c). Each phase of the swim-start must be carefully coordinated to maximize the contribution to overall performance.

Tremblay and Fielder (2001) observed that swimmers try to obtain the highest explosive power from the block, which requires a compromise between the optimal movement time and the time taken to push off from the block. To optimize the block phase, Mason et al. (2006) found that expert swimmers, regardless of the start technique, generated higher average acceleration on leaving the block and that take-off angles were important discriminating parameters of performance. Wilson and Marino (1983) specifically studied the influential factors in the aerial phase and reported low take-off angles by elite swimmers ($21.25 \pm 5.59^\circ$) and a flight time phase of 0.30 ± 0.04 s. Tremblay and Fielder (2001) reported that the best swim-starts were achieved by leaving the block quickly, traveling a great distance in the air, and making a clean entry into the water with powerful underwater leg propulsion. The importance of a clean entry and a streamlined glide position to maintain the velocity acquired during the aerial phase was emphasized, as was the need for swimmers to delay the moment when they begin stroking (i.e., a velocity greater than the instantaneous average swimming velocity) (Sanders and Byatt-Smith, 2001). Zatsiorsky et al. (1979) found correlations between the glide phase and the 5.5-m time ($r = 0.60$ and $r = 0.94$ at $p < 0.05$). Pereira et al. (2006) investigated the underwater phase and showed significant correlations between the maximum depth reached during the glide and the average velocity of the phase with the 15-m time ($r = 0.515$ and $r = -0.645$). Less skilled swimmers showed strong significant correlations ($r = 0.98$ at $p < 0.05$) between the underwater phase and the start time (Arellano et al., 1996). Bloom et al. (1978) showed that leaving the block quickly was important, but that sufficient time on the block was also important to generate force and maximize initial velocity. Another study of underwater phases (Sanders, 2004) showed that expert swimmers maximize propulsion and minimize resistance notably by adopting a streamlined position and selecting appropriate glide times and underwater propulsion times before commencing free stroking.

Skill level comparison

Few studies have directly compared expert and non-expert swimmers to characterize performance using all the start variables. Benjanuvatra et al. (2007) showed significantly higher block values for horizontal impulse (3.60 ± 0.23 versus 3.17 ± 0.30 N/kg) and lower take-off angles ($27.45 \pm 5.99^\circ$ versus $39.62 \pm 13.19^\circ$) for elite swimmers. This indicated the greater efficiency in the impulse of the expert swimmers (better orientation of forces compared with the overall direction of the movement). Furthermore, the expert swimmers tried to go as fast and far as possible when starting, whereas the non-experts had other aims: they tried to organize their limbs with regard to gravity by managing the translation-rotation compromise during the push on the block, or they tried to be hydrodynamic during the air-water transition of water entry.

Expertise can also be assessed in terms of adaptability (Warren, 2006), as when a swimmer performs a start with a non-preferred technique. Bartlett et al. noted that sport biomechanists consider movement variability to be an important element for analysis (Bartlett, 2004, 2007a; 2007b). These authors showed that movement variability has a functional role and can be analyzed at three levels (Bartlett et al., 2004; 2007b).

The first level of analysis is between trials using the same technique (i.e., inter-trial and intra-individual variability). By assessing multiple repetitions of the same skill, researchers determine the phases during which variability occurs and then seek to understand how the task performance may have been altered (Bartlett et al., 2004). For example, in a study based on only three trials for expert and non-expert swimmers, no significant differences were found in the intra-class correlations (ICC) for each swimmer of the two groups, nor did the expert swimmers show better reproducibility than the non-experts (Vantorre et al., 2010c).

The second level of analysis is between the performances of swimmers with the same or different levels of expertise (i.e., inter-subject variability). Vantorre et al. (2010c) also compared elite and non-elite swimmers performing swim-starts using ICCs. The experts showed shorter impulse times but higher impulse values in the horizontal and vertical axes than the non-expert swimmers. The data indicated that the expert and non-expert swimmers used different strategies for the start and that each group approached the task in a qualitatively different manner. For the non-expert swimmers, the main goal was to not to lose too much time on the start, especially between the reaction to the starting signal and the impulse on the block. In contrast, the expert swimmers sought to find a compromise between a short block phase and a powerful and well-oriented impulse. A second goal for the non-expert swimmers was to manage the transitions between gliding, leg kicking and full swimming, while the expert swimmers tried to conserve velocity by adopting a more streamlined body position in order to start full swimming as late as possible.

Vantorre et al. (2010a) and Seifert et al. (2010) used cluster analysis as an additional technique for inter-subject analysis to evaluate the role of variability. Seifert et al. (2010) showed that expert swimmers organized

themselves differently and used arm and leg movements during the aerial phase to enter the water cleanly and as far as possible from the block. Vantorre et al. (2010a) showed that expert swimmers developed different strategies from the start signal to the 15-m mark to achieve their optimal performances.

The last level of analysis is inter-preference variability (i.e., between a preferential technique and a non-preferential one), which is believed to be useful in determining the adaptability of performers as they manage changes in conditions. Vantorre et al. (2011) studied elite swimmers who habitually used a grab start as they used both the grab start and the track start, the non-preferred skill. In line with previous work (Benjanuvatra et al. 2007), this study showed less loss of angular momentum in dimensions other than the direction of movement when the swimmers used the preferred grab technique and lower efficiency using the non-preferred track start technique, in part due to a twisting effect of this technique.

Vantorre et al. (2010a) used cluster analysis and showed that expert swimmers are distinguished by start profiles, suggesting that a range of strategies can be used to achieve high start performance. This range of profiles confirmed that each constraint may have more than one solution and, thus, that expertise is not necessarily characterized by decreased movement variability. Instead, variability may well reflect personal responses based on anatomy, with each individual finding a different motor solution to achieve a “good start.” Indeed, in competition, one observes different start techniques and variations of the same technique existing side by side.

The analysis of variability suggests that practitioners can evaluate which start technique is best suited to a given swimmer from among the range of possible techniques. This is a process that requires tracking performance changes over time and at the individual scale. In the final section, we review how swim-starts have evolved and provide practitioners with an overview of the strengths and weaknesses of the start techniques identified in the literature. One of the key points to emerge from this review is that swim-start techniques have co-evolved (and will likely continue to do so) with such factors as rule changes and starting block technology. In this respect, variability analysis may be a promising method for remaining up to date with changes in the sport.

The start techniques

Traditional start techniques

Swim-start techniques have evolved. An early technique from 50-60 years ago is the conventional or arm swing start. Some years later, Zatsiorsky et al. (1979) identified two styles of the conventional start (with forward arm oscillation and complete oscillation), and Lewis (1980) observed three types (with arms back, with arms swinging back, and with circular oscillation of the arms). According to Bowers and Cavanagh (1975) and Lewis (1980), the conventional start allows longer flight distances than the grab start, largely due to the longer block phase. The conventional start is still sometimes recommended for relay races, where the increasing arm swing on the block

does not appear to influence the swimmer changeover execution time. Otherwise, it is rarely seen in competition today. For example, at the Sydney Olympics in 2000, no swimmer used this technique except in relays (Sanders, 2004).

As the start techniques evolved, the track start appeared and was popularized by Rowdy Gaines, winner of the 100-m freestyle at the 1984 Olympic Games in Los Angeles. This technique was borrowed from athletics (track and field), with swimmers putting one foot on the front edge of the block (track start) instead of two (grab start) (Krüger et al., 2003; Miller et al., 2003; Takeda and Nomura, 2006). With the track start, swimmers can place the body weight on the front edge (front-weighted track start) or the back of the block (track start slingshot) (Vilas-Boas et al., 2003, 2000; Welcher et al., 2008). With the grab start, the hands grip the front edge of the block between the legs or the front outer edges of the block (Lewis, 1980).

Contemporary techniques

Some start styles combine several techniques, such as the bunch start, where swimmers place their feet for a track start and the hands for a conventional start (Ayalon et al., 1975). Galbraith et al. (2008) studied the effect of arm and hand positions with a modified one-handed track start. Another example is the tuck start, in which the forward movement of the center of gravity is used by positioning the compact body while the swimmer grabs the sides of the block (Woelber, 1983). The purpose of the tuck start is to reduce the time interval between the start signal and entry into the water (Woelber, 1983). A version of the tuck start, called the handle start, was developed to explore the effect of placing the center of gravity in the most forward position (Blanksby et al., 2002; Pearson et al., 1998). This study followed the development of the Anti-Wave SuperBlock with handles on the sides that the swimmers can grab behind the body (Pearson et al., 1998). However, this type of starting block – even if it was approved by FINA – is not the norm in international competition. This is particularly true since the last regulatory changes.

Future of the start

By adding an adjustable incline, the Omega kick-start block has become the favored block for the track start (improving it by adding solid support for the rear foot) (Takeda et al., 2012). Studies indicate a wide range of behaviors from which swimmers can choose, which helps to explain some of the difficulty in determining a single “best” technique for optimal performance for various strokes and body morphologies. In any case, few studies have sought to compare the techniques.

Despite the lack of comparative data, it is nevertheless reasonable to question whether a single ideal start model exists. Individuals present with different physical, physiological, and anthropometric characteristics. Therefore, it is likely that several techniques or combinations of techniques can be used to achieve expertise in the swim-start, and research has shown that a number of profiles do indeed exist. This

concept of inter-individual variability is particularly relevant to understanding the nature of expertise, but it complicates the job for coaches, who might very well prefer to have a single profile of a world champion swimmer that they can encourage their swimmers to work toward.

Importantly, in the few studies comparing start techniques (the grab start and track start), a key limitation has been that in almost all cases the authors did not consider the preferred technique of the swimmers (Blanksby et al., 2002). Krüger et al. (2003) did so (the track start for 2 and grab start for 5), but this information was not included in their analysis of the results. Yet it is quite likely that experience with a technique may have an impact on start parameters and performance. Indeed, Vilas-Boas et al. (2003) and Vantorre et al. (2011) took this into consideration by using a dual approach that mixed the technical effect and the effect of preference. This distinction between the "technical" and "preferential" effect is essential.

Conclusion

This review has contextualized the analysis of the swimmer start in terms of its purpose: to balance arriving as quickly as possible at the end of the start with the added task of setting up the remaining portion of the swim. The various phases of the start can be described as a series of compromises that have to be made. The block phase, for example, requires a compromise between saving time by leaving the block quickly and pushing off it for a relatively long time to generate a high enough impulse to drive the swimmer as far as possible, thereby ensuring water entry at high velocity. The notion of compromise also applies to the aerial phase, with the possibility of choosing a trajectory for water entry through a hole, a flat trajectory and entry, or a trajectory that lies somewhere in between. However, a common characteristic of these strategies is to achieve aerial phases with a segmental alignment when the body breaks the surface of the water. The swimmer's goal for the start also affects the choice of strategy to achieve a "good start." Non-expert swimmers prefer to begin stroking earlier than expert swimmers because they have not yet mastered the phases of the start well enough for it to be a real advantage over beginning to stroke. Individual characteristics also influence how each swimmer optimizes the start phases: sprinters versus long-distance swimmers, high versus low vertical leaps, large versus small body parts, and so on. In this sense, variability can be contextualized as functional and not an error with regard to deviation from the "only way" to achieve the best start. The coexistence of several start techniques – position of the feet on the block, arm movement during the flight phase – confirms the assumption of compromise and adaptation as inherent challenges for the swim-start.

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Key points

- Swimmers meet two main constraints during the start movement: travelling more distance in the air (to get less resistance) and rotate to enter properly in the water.
- Swim start is a sum of compromises in all parts of it, and swim-start expertise is distinct from swim stroke expertise corresponding to best ways to manage these compromises.
- Variability found is contextualized as having a functional role and operating across multiple levels of analysis.