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Research article

Mechanical characteristics of swimming start: kinematics of track and grab techniques

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Abstract

Historically, various techniques have been employed for swimming starts; however, contemporary advancements in the design of starting blocks have led to the predominance of the Track and Grab starts among competitive swimmers. This study aimed to investigate and compare selected kinematic parameters between these two swimming start techniques. The study participants included eight swimmers with a mean age of 13 ± 1.7 years, a mean height of 158 ± 7 cm, and a mean weight of 57.8 ± 16.5 kg, each possessing an average of 3 ± 1.5 years of competitive experience. A two-dimensional motion analysis was conducted using high-speed cameras to collect kinematic parameters, which included flight distance, platform separation angle, water entry angle, angular velocities of selected joints, and the horizontal linear velocity of the pelvis at the moment of detachment from the platform. Kinematic data were captured by two cameras positioned on either side of the pool, recording at 120 frames per second. The results indicated a significant difference between the two techniques regarding the angular velocity of the left knee (Grab= 41.1(5.8) and Track= 80.9(5.0) (Deg./s), p= 0.024) and the linear velocity of the pelvis (Grab= 2.0(6.9) and Track= 2.1(3.1) (m/s), p= 0.036) prior to water entry, with the Track start technique demonstrating superior performance in both parameters. Based on these findings, it can be concluded that the track start demonstrates superior performance regarding these variables, providing increased initial speed upon entering the water and facilitating a more effective trajectory thereafter. While no significant difference was observed in flight distance, the variations in linear velocity may provide valuable insights for swimmers and their coaches.

Keywords: Sport biomechanics, Swimming start, Kinematics, Track and grab, Flight distance.

1- Introduction

Mechanical engineering applies the science of mechanics to the design and analysis of tools, equipment, and machines that human has designed and built to facilitate tasks [1-3]. The focus of biomechanics is on applying mechanical principles to the performer themselves [4-6]. This includes examining the stresses imposed on the individual with the aim of safety and injury prevention, as well as analyzing the dynamic execution of movements to enhance performance. The kinetic- and kinematic-based analysis of sports techniques is among the most common research topics in sports biomechanics, dedicated to improving athletes' performance.

Swimming is a sport in which athletes compete while suspended in water, propelling their bodies forward against water resistance, which is significantly greater than that encountered in air. As a result, swimming is often considered less effective than many other sports [4], [5], [7], [8]. In competitive swimming, enhancing performance is paramount. A swimming competition consists of four interrelated phases: the start, freestyle, turn, and finish phases [9]. The start is the initial skill executed by swimmers, and when performed correctly, it can reduce overall swimming time [10]. Swimming instructors face the challenge of identifying the most suitable starting technique for swimmers based on their anthropometric characteristics. The swim start is typically divided into three sub-phases: the on-block phase, the flight phase, and the underwater phase [11], [12].

The initiation of movement in swimming, referred to as the "start," can occur either by jumping from the pool platform or from within the water at the edge of the pool. Over the years, various starting techniques have been developed, each serving its purpose during its respective time; however, modern starts from the platform are primarily categorized into two methods: the traditional grab start and the track start, reminiscent of track and field starts [13]. The primary distinction between these techniques lies in how the lower limbs are utilized on the platform to propel the body forward. The Grab start is characterized by a two-legged pull-out technique, akin to a two-legged jump. In contrast, the Track start employs a two-speed mechanism, initiating propulsion with the back leg followed by the front leg [14]. The grab starts, introduced by Hanaur in 1967, quickly gained popularity [15]. This technique differs from earlier methods in that the swimmer grips the front edge of the starting platform with their fingers and awaits the sound of the starting pistol. Upon hearing the signal, the swimmer propels their body forward from the platform. In contrast, the track start represents a recent adaptation of the grab start, designed particularly to minimize the risk of injury. This method has been adopted by numerous international swimmers. The primary distinction between the track start and the conventional grab start lies in the swimmer's positioning on the starting platform. The swimmer assumes a stance similar to that of a sprint starter, with one leg positioned at the back. Figure 1 depicts the positioning of these two starts.

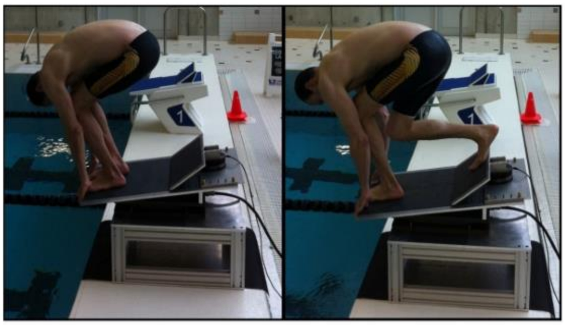

Fig. 1 Positioning of the Grab (Left) and Track (Right) starts. [16]

Swimmers often choose a starting technique based on personal belief, experience, and comfort rather than concrete scientific evidence. Some studies [17] have reported no significant differences in the effectiveness of the Track and Grab start techniques. Conversely, other research [18] has indicated that the Track start technique is superior. In a study by Peterson et al., biomechanical parameters were assessed to describe ventral start performance in swimming [19]. Takeda et al. examined the individual hand and foot reaction forces during the execution of the kick-start technique [20]. Veiga et al. investigated how starting and turning performances affect subsequent swimming parameters, comparing starting and turning velocities with swimming performance during the emergence and mid-pool segments [21]. Slawson et al. explored the impact of knee angle during the platform contact phase. They investigated the effects of foot positioning on the starting performance of ten male national-level speed swimmers [22]. Participants performed maximum power experiments using different foot positions during the start. The results indicated that the optimal position for achieving peak vertical force occurred when the angle of the rear knee was between 80 and 90 degrees. Conversely, peak horizontal force was recorded when the knee angle was approximately 100 to 110 degrees.

Honda et al. were the first to examine the impact of the platform on starter performance, as well as the effect of swimmers' positions on the platform prior to the starting signal [23]. Their findings revealed that changing the three launch pad positions did not significantly affect dive times; however, a greater reliance on the rear foot of the platform resulted in increased velocity. Notably, no significant differences were observed in the time taken to reach 7.5 meters. Research in the field of swimming, and in particular in swimming start, has continued in recent years, with numerous scholars publishing valuable articles on the topic [24-26].

Despite the growing interest in biomechanics of swimming start, limited research has been conducted in our country. This gap has contributed to the lack of success among numerous swimmers in these areas. Thus, it is imperative to undertake precise and meticulous biomechanical studies and analyses in this field, influence performance for Iranian swimmers.

2- Materials and methods

In this study, comparative and descriptive methods were employed to explore the relationships between kinematic variables of these two swimming techniques: the grab start and the track start. Eight adolescent swimmers participated in the study, with a mean age of 13 ± 1.7 years, a mean height of 158 ± 7 cm, and a mean weight of 57.8 ± 16.5 kg. Each participant had an average training history of 3 ± 1.5 years and reported no history of lower limb injuries, including ligament injuries, particularly anterior cruciate ligament, osteoarthritis, lower limb joint sprains, muscle strains, tears, or fractures, nor had they undergone any surgical procedures on lower limb joints. All athletes were in excellent health without injuries at the time of the investigation.

Prior to testing, written consent was obtained from all participants to ensure their willingness to take part in this research. For the kinematic analysis, two CASIO ZR-200 high-speed video cameras were utilized to capture body movement. These cameras feature a 12.5x optical zoom and can record at frequencies of 120, 240, and 480 frames per second, with 120 frames per second selected for recording the movements in this study.

Initially, both types of starting techniques were thoroughly reviewed, and comprehensive explanations were provided to the swimmers. Following this, each swimmer completed a consent form, and their weight, height, and limb lengths were measured. To facilitate participant comfort and minimize intervention, no markers were applied to the swimmers' bodies. Prior to testing, participants were permitted to warm up and practice. To calibrate the environment, a calibration frame was utilized, consisting of three calipers suspended from the pool ceiling at intervals of 0, 2.5, and 5 meters. As illustrated in Figure 2, two cameras were mounted on either side of the track, perpendicular to it, at the athletes' body level and positioned 13 meters from the starting area on tripods. The camera's field of view and zoom settings were selected to ensure the entire body of each swimmer was clearly visible upon entering the water. Filming commenced as soon as a swimmer indicated readiness on the start platform and continued uninterrupted until they crossed the 5-meter line. Each swimmer participated in two test trials, with one technique (either grab or track) performed at maximum effort in each trial. Tests were conducted with a three-minute rest interval between repetitions and a twenty-minute interval between each test, allowing for at least three successful executions to be recorded. Data from the two best performances, based on both technique and time, were considered for the variable calculations.

The biomechanical parameters examined in this study included kinematic data obtained from the recorded videos. These videos were analyzed using a custom 2D motion analysis software developed in MATLAB, which enables the extraction of joint coordinates frame by frame. The software consists of three components: calibration, positioning, and motion calculation.

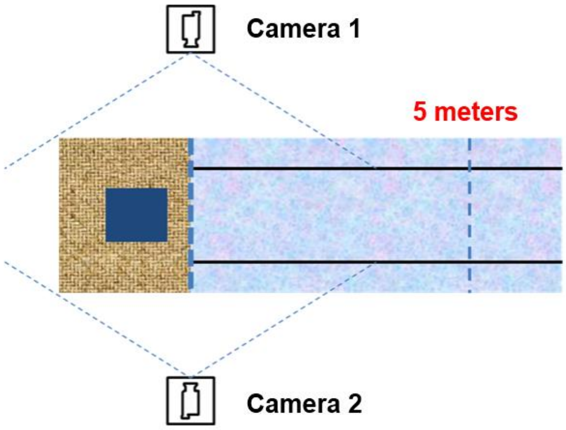

Fig. 2 Setting up the cameras

Initially, the left and right calibration frames are established in the calibration section by selecting the pixel coordinates of four calibration points and inputting their corresponding real-world coordinates. The following FLT calibration formula was utilized to calibrate the system and obtain the necessary calibration coefficients:

$$\begin{aligned} C1\,u + C2\,v + C3 &= x\,(1 + C7\,u + C8\,v) \\ C4\,u + C5\,v + C6 &= y\,(1 + C7\,u + C8\,v) \end{aligned} \tag{1}$$

In this context, C1 to C8 represent the coefficients of the FLT, while u and v denote the digitized image coordinates, and x and y represent the Cartesian real coordinates of the calibration points. In the positioning section of the software, videos of the swimmers' performances are imported, and the frames corresponding to each performance are displayed in sequential order. Each video comprises an average of 92 to 115 frames. During the analysis, eight anatomical points are identified in each frame—namely the head, shoulders, elbows, wrists, hips, knees, ankles, and toes—by clicking on them with the mouse. As illustrated in Figure 3, the frames capturing the moments of separation, as well as the front and rear leg movements, are appropriately marked. This process continues from the first frame until the final frame of the performance is marked. Subsequently, utilizing the calibration file generated in the first section, the actual coordinates of the joints are calculated. Notably, the obtained limb lengths were compared with the measured lengths, revealing no significant discrepancies.

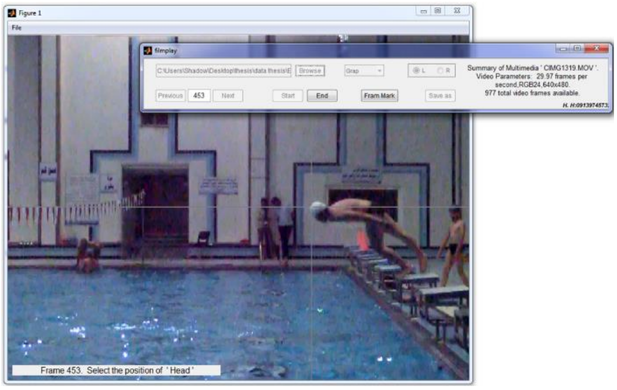

Fig. 3 Custom 2D motion analysis software developed in MATLAB

In the subsequent phase of the program, a sensitivity analysis was conducted to fit the motion curve of the right-hand fingers to the optimal curve, minimizing potential noise at each data point across all trials. Following this, the relative angles of the joints at each frame were calculated using trigonometric formulas. To ensure uniformity and facilitate analysis, the duration of each trial was divided into one hundred equal segments, and the distances for each trial were interpolated accordingly. The graphs for two selected trials were averaged for each technique. By deriving the angular position over time, we obtained the corresponding angular velocity profile. Additionally, the linear position of the hip joint was analyzed to derive the linear velocity of the pelvis. This was accomplished by drawing a line from the hip to the right ankle at the moment of takeoff from the platform to determine the angle of separation, as illustrated in Figure 4. Similarly, a line was drawn from the shoulder to the fingertips at the moment of water entry to determine the angle of entry, as shown in Figure 5. The fourth order polynomial fitting method was employed for this analysis.

Fig. 4 Angle of separation

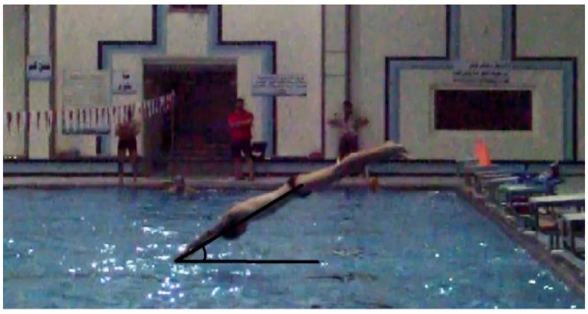

Fig. 5 Angle of entry

In this study, MATLAB 2013 was utilized to process images captured during athletes' performances, allowing for the extraction of limb and joint positions as well as timing information. This software also facilitated the calculation of key biomechanical parameters, interpolation, curve fitting, and diagram generation. Additionally, Excel 2013 was employed to organize and classify the extracted values pertaining to criterion variables and to compute the mean and standard deviation of the data. Statistical analyses were conducted using SPSS 21, where the non-parametric Kolmogorov-Smirnov test was applied to assess the normality of the data. Furthermore, the independent t-test was employed to evaluate the significance of differences between the variables associated with the two types of starting techniques.

3- Results

This research focused on selected kinematic parameters associated with two types of swimming start techniques (grab and track start) among swimmers with a mean age of 13 ± 1.7 years. Following the previously described research design and methodology, this study was conducted descriptively. All participants performed their tests under controlled conditions to ensure consistency. To analyze the collected data, the mean and standard deviation were calculated to describe the kinematic information obtained from the video recordings. To compare the means of the kinematic data and assess significant differences, a paired sample t-test was employed. Table 1 presents the mean and standard deviation of the general characteristics of the participants, including height, weight, age, and athletic experience.

Table 1: Statistical indicators related to height, weight, age, and sports history of participants

Number of swimmers	Activity history (year)	Age (year)	Weight (kg)	Height (cm)
8	3 ± 1.5	13 ± 1.7	57.8±16.50	158 ± 7

Table 2 presents the selected kinematic parameters, including flight time, starting range, water entry angles, and hip speed, which serves as an estimate of overall body speed. As indicated in Table 2, the average flight phase duration is longer for the grab start technique. Conversely, although the average contact phase time on the platform is greater for the track start, the total start time is longer for the grab technique, as reflected in the overall start time parameter. Notably, while the total start time for the grab technique is extended, the average flight distance achieved is shorter compared to the track start. However, these differences were not statistically significant. Additionally, the average angle of detachment from the platform is greater in degrees for the track start technique, and the average angle of entry into the water is also higher in this technique. These angles influence the distribution of horizontal and vertical speeds, contributing to the swimmer's optimal progression by achieving an appropriate ratio. Nevertheless, the observed differences in this study did not reach statistical significance. The angular velocities of the hip and knee joints are also presented in Table 2. It is noted that the average angular velocity of the hip joints is higher on both the right and left sides for the track start technique. Conversely, the average angular velocity of the right knee is greater in the grab start, while the average angular velocity of the left knee is higher in the track start.

Notably, the difference in the angular velocity of the left knee between the two types of starters is statistically significant. Figure 6 illustrates the angular velocities during the flight phase for the hip, knee, shoulder, and ankle joints. For the grab start, the average angular velocity of the shoulder is higher on both the right and left sides compared to the track start.

Table 2: Selected kinematic parameters of Grab (G) and Track (T) start

Variable (Measurement Unit)		Start Type	Mean (SD)	t	Sig. (2-tailed)
Flight Time (ms)		G	400 (50)	0.959	0.392
		T	366 (33.5)		
Platform Contact Time (ms)		G	550 (125.8)	-0.260	0.808
		T	572 (75.1)		
Total Start Time (ms)		G	950 (76.4)	0.193	0.857
		T	939 (67.5)		
Flight Distance (mm)		G	2981 (245)	-0.065	0.951
		T	2994 (252)		
Separation Angle from Platform (Deg.)		G	31.2 (2.6)	-1.438	0.224
		T	36.4 (5.7)		
Water Entry Angle (Deg.)		G	32.8 (0.4)	-0.181	0.865
		T	33.2 (3.9)		
Hip Angular Velocity (Deg. /s)	Left	G	140.2 (6.8)	-0.391	0.696
		T	150.2 (6.9)		
	Right	G	137.2 (1.7)	-0.471	0.638
		T	150.2 (5.2)		
Knee Angular Velocity (Deg. /s)	Left	G	41.1 (5.8)	-2.269	0.024 *
		T	80.9 (5.0)		
	Right	G	37.1 (9.9)	0.317	0.752
		T	31.2 (2.1)		
Hip Linear Velocity during Flight Phase (m/s)		G	2.0(6.9)	-2.111	0.036 *
		T	2.1 (3.1)		

Additionally, the average angular velocity of the right ankle is greater in the grab start, whereas the average angular velocity of the left ankle is higher in the track start. The average linear velocity of the pelvis during the flight phase is significantly higher for the grab start technique compared to the track start, suggesting that a faster start may be recommended based on this criterion. The results indicate that both flight time and total start time are longer for the grab technique. Although these differences were not statistically significant, even small discrepancies can result in time losses for swimmers. Therefore, from this perspective, the track start may be considered the faster technique. Moreover, the contact time with the platform is longer for the track start, likely resulting in a greater impact from the platform. This increased impact contributes to a larger momentum shift and greater speed, leading to a shorter flight time for the track starter. The longer distance traveled during the flight phase, combined with the shorter flight time, further supports the assessment of higher flight phase speed for this technique, which aligns with the increased impact from the platform. Utilizing force from both feet can help explain the influence of the platform's reactive force. Additionally, the incorporation of a force plate on the starting platform may provide a more objective assessment of this hypothesis.

The separation angle from the platform is greater in the track start technique, which influences the distribution of vertical and horizontal speed components. A larger vertical component can result in extended flight time, whereas a greater horizontal component contributes to increased forward speed or range. In contrast, the grab start technique exhibits longer flight times yet shorter distances, seemingly contradicting the expected outcomes based on its lower angle of detachment from the platform, which suggests a shorter flight time and longer range. It is crucial to consider that if the speed values remain constant, one might infer that the speed of the grab starter is lower than that of the track starter, thus indicating a more significant platform impact for the latter. Additionally, the angle of entry into the water for the grab starter is lower, which may further decrease underwater time. Given the forces of fluid resistance and swimmers' inclination to minimize wave drag, the track start can be considered a potentially superior technique as it enhances underwater distance after water entry.

The angular velocities of the hip and knee joints are also important factors influencing starter performance. The anticipated faster opening of the hip joint in the track start suggests that increased vertical speed should enhance flight time. Nonetheless, merely elevating the vertical speed of the hip joint may not suffice to optimize the efficiency of the track start. While one might theorize that a reduction in thigh angular velocity could yield better conditions, this was not observed for the grab start.

The significant difference in knee extension speed between the two starters can be attributed to the positioning of the legs in each technique, ultimately affecting horizontal and vertical speeds. Both the knee and hip joint extension speeds significantly influence vertical velocity and are justified by their respective starting positions. The track start technique exhibits greater angular velocities and, correspondingly, higher range and velocity, suggesting that while increased angular velocity may initially appear to hinder performance, it can actually enhance overall efficiency.

The linear velocity of the hip joint serves as a representative measure of overall velocity. Although the mean differences between the two techniques are significant, the grab starter shows an advantage in this parameter.

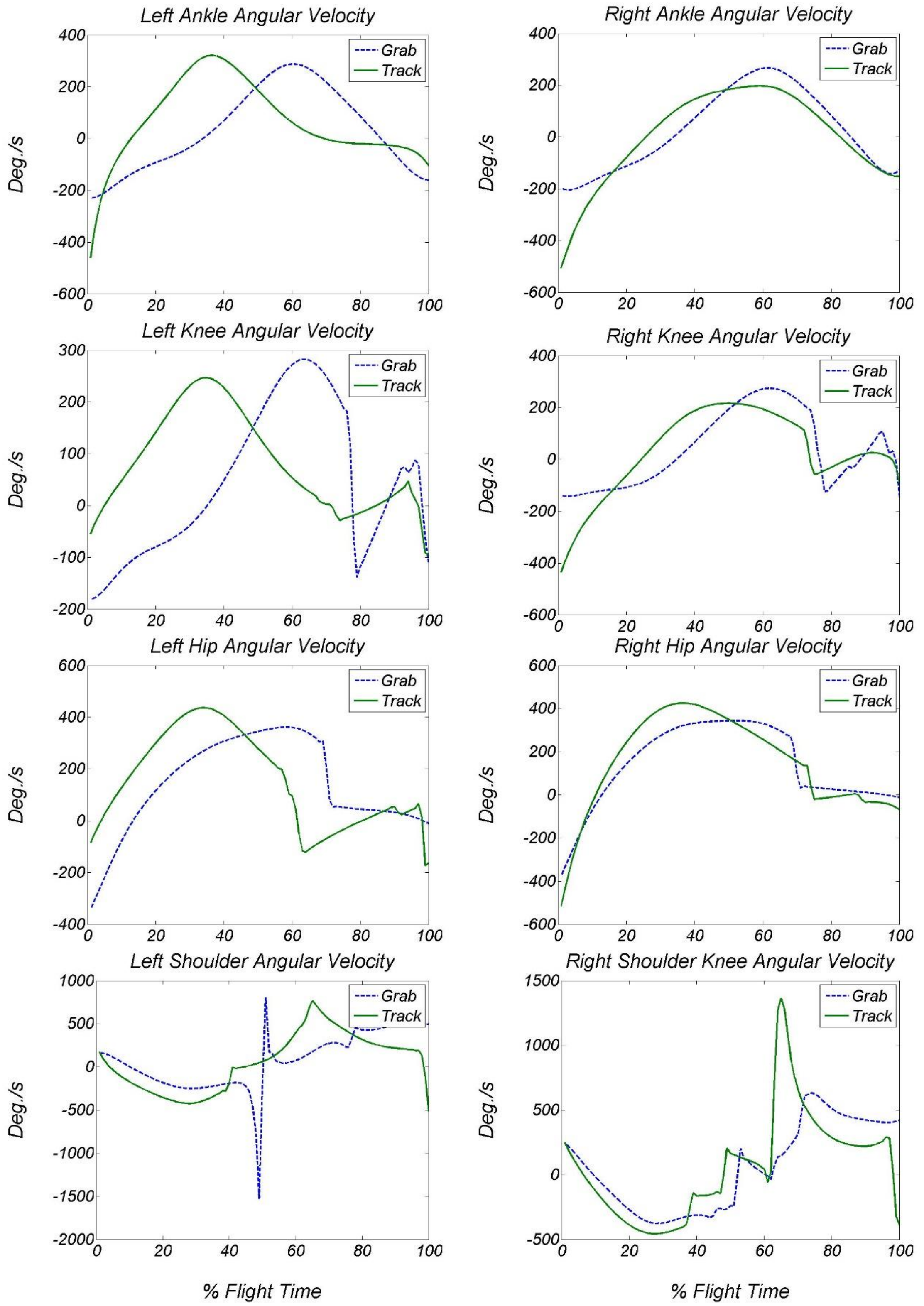

Fig. 6 Angular kinematic parameters in different start techniques

It appears that horizontal and vertical velocities must be analyzed separately to reassess previous findings and validate the underlying theories. Calculating these parameters reveals that the track start has a greater horizontal speed of the hip joint. Based on the study's results, the track start can be recommended as a superior technique for swimmers in terms of flight time and distance. However, it is essential for coaches to recognize individual differences in muscle strength among athletes and to evaluate various techniques on a case-by-case basis, identifying the most suitable approach for each swimmer according to the criteria proposed in this study. The average data for the eight swimmers involved in the study is presented in Figure 6. These findings are in contrast to those reported by previous researchers. Some researchers concluded that the track start technique exhibits shorter platform contact time and flight time compared to the grab start [27-29]. However, the present study found no significant difference between these two start techniques in terms of start time. This discrepancy may plausibly be attributed to the professional level of the participants involved in this study and their reduced reliance on the platform contact phase for a quicker entry into the water.

This result also differs from the findings of some previous researchers. Shin and Groppeł concluded that, although participants exhibited a faster toe-off phase in the track method, the grab start resulted in a longer flight distance [29]. However, the present study found no statistically significant difference, and the slight increase in flight distance observed in the track method may be attributed to greater utilization of the platform contact phase, a departure angle closer to the optimal angle, and higher horizontal linear velocity at the hip during this start.

4- Discussion

This study aimed to compare selected kinematic factors between two types of swimming start techniques—the track start and the grab start—using camera data from semi-professional swimmers. The analysis was conducted through 2D motion analysis, with all data extraction and calculations performed using custom codes written in MATLAB software. The resulting information was subsequently analyzed using statistical software.

Among the kinematic parameters examined, a significant difference was found only in the angular velocity of the left knee before entering the water, as well as in the horizontal linear velocity of the hip prior to entry. The average contact time with the platform was higher for the track start, with a difference of 22 milliseconds, likely attributable to a delayed departure from the platform. The start time for the grab start was, on average, 11 milliseconds longer.

In terms of joint angular velocities before entering the water, the average angular velocity of the left knee was significantly greater in the track start by 39 degrees per second compared to the grab start, which may be associated with the swimmer's stance and effort. Additionally, the average horizontal linear velocity of the hip was significantly higher for the track start, possibly resulting from greater force applied by the foot to the platform. Based on these findings, it can be concluded that the track start demonstrates superior performance regarding these variables, providing increased initial speed upon entering the water and facilitating a more effective trajectory thereafter. Therefore, it is recommended that, in selecting this technique, attention be paid to certain considerations, such as carefully choosing the take-off angle and utilizing a platform to generate greater impulse and achieve higher linear velocity for the hip joint. Appropriate evaluation and implementation of these factors are advised. Considering the findings of this study, it is advisable that coaches refrain from selecting a specific start technique and instead base their choice on the swimmer's muscular strength, ability to generate force or power in the dolphin kick during underwater phases, and overall swimming performance.

Because of some limitation of this research, it is recommended that future studies investigate start platforms equipped with adjustable footrests and utilize underwater-capable video recording cameras to analyze the performance over a distance of up to 15 meters. Additionally, the use of waterproof force plates to obtain kinetic factors, three-dimensional motion analysis, and electromyographic assessment of muscle activity are other proposed avenues. These approaches should be complemented by the collection of kinetic and kinematic data, with simultaneous analysis of the upper and lower extremities to provide comprehensive insights.

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Declaration of competing interest

The authors declare that no conflict of interest exists regarding the submission of this article, and all authors have approved the manuscript.

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