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Analysis of angular momentum effect on swimming kick-start performance

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ABSTRACT

The aim of this study was to analyse the mechanics of rotation and the temporal, angular and kinematics variables during the aerial phase for the kick-start with respect to the grab start. Nine elite swimmers (70.0 ± 7.7 kg; 178 ± 9.4 cm; 24.5 ± 5.3 years; 824 ± 119 FINA points scoring) performed the starts on the OMEGA OSB11 starting block followed by 5 m gliding at maximum velocity. Nineteen comparisons of kinematics variables across start technique were performed with critical alpha adjusted using a Holm's correction to maintain an experiment-wise type I error rate of $p < 0.05$. The differences were statistically evaluated by T-test and Wilcoxon test. Significant advantages for the kick-start were observed in all temporal variables (except in the flight time) and in the vertical take-off velocity. Similarities in the centre of mass angular momentum at take-off (120.89 ± 17.66, 126.61 ± 13.51 $s^{-1}.10^{-3}$, p-value < 0.294; kick-start and grab start) caused that KS did not increase the temporal advantages obtained on the block at 5 m distance. Two different rotational movements were found for both techniques. A displacement of the rear leg and front leg on the block and during the flight respectively permits a higher lower limbs position relative to the trunk at hands entry for kick-start. However, larger rotational movement of the trunk characterized grab start. It was concluded that shorter block times and rotational displacements of the lower limbs on the block and flight phase are the key of the best performance for kick-start at 5 m distance.

1. Introduction

The swimming start has always been in continuous development with the objective to find a technique that is more beneficial to swimmers. The most recent dramatic advancement related to equipment appeared in 2009 when the International Swimming Federation (FINA) approved the new starting block with a back plate (FR 2.7 Starting Platforms in FINA's rules) that features an "adjustable, slanted footrest". This rear back plate is placed 0.35 m from the front edge of the block with an inclination of 30° relative to the main plate. It is a mobile support that provides a steady base for the swimmers' rear foot. It can be set to different positions from the front edge of the block.

This starting block modification induced changes in the start technique compared with the previous standards the Grab Start (GS) or Track Start (TS). Swimmers are placed in an asymmetrical position with one foot on the front edge and one on the rear back plate. The literature named this modification of the TS as Kick-start (KS) (Barlow et al., 2014; Honda et al., 2010; Ozeki et al., 2012; Slawson et al., 2012). All studies that compared the start from the platform with back plate (KS) and from the conventional platform (TS) showed advantages for the KS with respect to the horizontal and vertical take-off velocity as well as shorter block time, flight time and time to 5, 7.5, 10 and 15 m. (Beretić et al., 2012; Honda et al., 2012; Nomura et al., 2010; Ozeki et al., 2012).

Considering the feet position, the GS is the most opposite technique to the KS. This start is characterized by a symmetrical starting position, with both feet on the front of the platform. The starting block development as well as the above mentioned advantages for KS over TS and the decline in GS popularity in last years' competitions caused the lack of studies comparing the KS and GS. However, certain research about differences between these

Abbreviations: KS, Kick-start; GS, Grab start; HTO, Hands take-off; BT, Block time; FT, Flight time; ET, Entry time; T5, Time to 5 m; TOA, Take-off angle; Trunk-front $leg_{take-off}$, Trunk-front leg at take-off; Trunk-front leg_{entry}, Trunk-front leg at hands entry; Trunk-rear $leg_{take-off}$, Trunk-rear leg at take-off; Trunk-rear leg_{entry}, Trunk-rear leg at hands entry; $Vx_{take-off}$, Horizontal CM velocity; $Vy_{take-off}$, Vertical CM velocity; *H*, Angular momentum

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techniques is interesting in order to establish the reasons of the superiority of an asymmetrical technique with the back support.

The most common variables used to compare swimming starts are temporal variables, angular variables, kinematic variables and kinetic variables. However, it is interesting to note that few studies have measured the angular momentum (*H*). *H* in the sagittal plane produced at take-off was shown to determine the swimmer's angular velocity during the flight phase and thus the entry angle and entry orientation (McLean et al., 2000). In this regard, Vantorre et al. (2010) after analyzing different start styles with the GS position on the block, they found angular momentum values at take-off of 14.7 ± 2.9 kg m^2/s during the “flat start” with a more horizontal body orientation at hands entry (entry angle: $23.4 \pm 2.2°$). In contrast, for the “pike start” with a more vertical body orientation at hands entry and “Volkov start” (characterized by an arm swing during the flight phase) larger angular momentum values at take-off (18.0 ± 0.6 kg m^2/s and 17.5 ± 0.4 kg m^2/s respectively) and larger entry angle ($24.6 \pm 4.8°$ and $28.2 \pm 2.5°$ respectively) were detected. Greater entry angle, which means a more vertical entry position, allows the swimmers to dive deeper. This fact implies lower hydrodynamic resistance as well as lower speed decrease at water entry, which leads to an underwater performance improvement (Elipot et al., 2009; Holthe and McLean, 2001; Miller et al., 2002). For this reason, achieving a higher angular momentum on the block and the manipulation of the body segments to control the sagittal plane moment of inertia of the body and angular velocity during the flight phase seem to be important factors of swimmers' start performance.

Currently, the findings about *H* reported that higher values at take-off increase the body rotation during the flight phase and leave a steeper water entry (McLean et al., 2000; Vantorre et al., 2010). However no study analyzed the rotational movements produced during the block phase and flight phase in swimming starts. Therefore the aim of this study was to analyse the mechanics of rotation on the block and during the flight phase for KS to understand the angular momentum contribution in the body rotation (with respect to the whole body centre of mass and the centre of mass of each body segment). The values obtained for KS were compared with the values obtained for GS. Currently, swimmers do not use frequently the GS, however we considered this technique the most appropriated to compare the values because of the different positions of the feet. Additional temporal, angular and kinematic variables were analysed.

2. Material and methods

2.1. Participants

Nine elite swimmers from the Spanish National Team (5 males and 4 females) participated in this study (body mass 70.0 ± 7.7 kg; height 178 ± 9.4 cm; age 24.5 ± 5.3 years). FINA Points Score was calculated in order to quantify the competitive level of the swimmers. Based on the best time of the main event, a point score was ascribed to each swimmer. The FINA Points of the study sample were 824 ± 119 points. The participants signed an informed consent and the procedures used for this analysis were approved by the University of Granada Ethics Committee.

2.2. Procedures

The data were collected during a training session at the High Performance Training Centre of Sierra Nevada. Each swimmer performed 10 starts in a counterbalanced order (GS and KS) from a starting block (OMEGA OSB11). The swimmers preferred the KS starting technique. However, in previous years they competed and trained with GS, what means everyone has a remarkable experience with both techniques. When performing KS, the swimmers placed their usual rear leg on the back plate support (6 right and 3 left). After the trigger sound, audible to the swimmers and visible to each camera with a flashing light, the swimmers performed a dive followed by a glide in order to discard the effect of possible differences in the profiles of water entry. The trial with the best performance at 5 m was included in the analysis. Each trial was recorded above the water by four High Definition Cameras Nikon 1 J1 (frame rate 60 Hz, resolution 1280×720 and shutter speed 1/1000) placed on both sides of the swimming pool, two on each side at 2.80 m and 10 m from the edge of the pool. One additional camera (Sony HDR-AS15) was placed underwater to get the time to 5 m, with the same recording setup as the above water ones.

A control object ($2 \text{ m} \times 1.55 \text{ m} \times 0.81 \text{ m}$) was used to calibrate the plane of motion. This structure, consisting in 12 aluminium rods and 34 control points, was placed on the water surface using a system of ropes. The real coordinates were reconstructed using a linear direct transformation (DLT) (3D DLT; Kwon 3D XP, 1996). A mean calibration error of 0.78 mm was obtained. Twenty-one points were manually digitalized to define the body model of 14 segments proposed by de Leva (1996). The Kwon 3D XP software was used for the digitalization and the subsequent kinematical analysis. All of the data were processed using a Butterworth Low-pass filter with a cut-off frequency of 6 Hz.

2.3. Variables

Temporal, angular and kinematic variables, including velocities and angular momentum, were analysed in this study. Table 1 shows the definition of each parameter. Mean curves of angular momentum versus time were represented for each segment CM and for the whole body CM. The timeline was normalized to 100% of the block time plus flight time (aerial phase) for each swimmer and each swim starting technique.

In order to eliminate the differences produced in the rotation due to the swimmers anthropometrical characteristics, the angular momentum was normalized based on the weight and height of each subject (Dapena, 1980; Kwon, 1996; Yeadon, 1990).

$$H_{\text{normalized}}(s-1) = \text{mass} \times \left(\text{height}^2\right) \times 10^3$$

2.4. Statistical analysis

Descriptive statistics were performed to calculate the mean and the standard deviation (SD) for each variable. After checking the data normality through the Shapiro–Wilk test, a paired *t*-test was applied to the variables that yielded a $p < 0.05$ in order to determine the differences between the GS and KS. The Wilcoxon test was applied to variables that were not normally distributed. Since multiple comparisons are made and in order to avoid incorrectly rejecting the null hypothesis, the significance level was adjusted using the Holm's correction such as the experiment-wise type I error rate was held to $p < 0.05$ by progressively adjusting the critical *p*-values of each test (Lundbrook, 1998). Effect size was calculated using Cohen's (*d*) to establish the strength of the differences between each technique. The scale to interpret the strength of the effect size was: 0–0.2 trivial; 0.2–0.6 small; 0.6–1.2 moderate; 1.2–2.0 large; 2.0–4.0 very large and > 4 almost perfect (Hopkins, 2002). The statistical analysis was performed with the statistical software SPSS v.19.0.

3. Results

3.1. Temporal, angular and kinematic variables

Table 2 shows the mean, SD, *p*-value and d for each variable analysed. Significant results were found in the HTO, BT, ET and T5 with higher mean values for KS. Similar results in the angular variables were shown for both techniques, although some differences related to the rear leg were found. We can observe very large differences in the trunk-rear leg$_{\text{take-off}}$ with a lower mean for GS (> 3.0). Regarding the velocities, larger differences were only observed when considering the vertical component of the CM velocity ($Vy_{\text{take-off}}$) ($d = 1.14$; $p < 0.004$) with higher mean values for KS.

3.2. Analysis of angular momentum

The *H* results are presented in two ways; firstly, as mean values at feet take-off (Table 2), and then as mean curves versus time between the starting signal and the water entry (Figs. 1 and 2). In both cases, the results are presented for the whole body CM and for each body segment CM. Based on the right-handed rule positive values of *H* indicated a clockwise rotation while a counterclockwise rotation was produced with negative values.