INTEGRATED KINEMATIC AND DYNAMIC ANALYSIS OF TWO TRACK-START TECHNIQUES

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The purpose of this research was to characterise and compare two variants of the track-start technique for ventral swimming races, using simultaneous and synchronised dynamic and kinematic data. Results indicated that the track-start variant with rear projection of the centre of gravity (TSR) is able to produce higher impulses and velocities, but also implies higher periods in the starting block and presumably higher hydrodynamic drag values during entry, that imposes identical total times for the first 6m of the race, when compared with the track-start technique with forward projection of the centre of gravity (TSF).

KEY WORDS: biomechanics, swimming starts, dynamometry, kinematics

INTRODUCTION: Swimming performance is determined by a many factors. Of these, the ability to perform the different technical tasks assume a critical importance. In swimming we should distinguish at least three technical domains: starting, stroking, and turning (Hay, 1986).

For years researchers have worked to evaluate the adequacy of different technical solutions for each of the problems faced by the swimmer. Some were centred on start techniques, both for ventral (Ayalon et al., 1975; Fitzgerald, 1973; Juergens, 1994; Kirmer et al., 1989; LaRue, 1985; Skin and Groppel, 1986; Zatsiorsky et al., 1979) and for backstroke swimming events (Scheuchenzuber, 1971; Wilson and Howard, 1983). Traditionally, studies of starts were centred on the comparison of different start techniques, mainly reporting the advantages and the disadvantages of the new techniques compared to the commonly used grab-start technique.

In 1973, a new start technique, the track start technique, was described (Fitzgerald, 1973). Since then, and mainly after the early eighties (LaRue, 1985), this technique increased in popularity in competitive swimming, especially for sprint events.

Presently, we may speculate that the grab-start still continues to be the most popular technique, and that a growing number of elite swimmers continue to experiment with the track-start. The observation of sprint competitions shows that at least two variants of the track-start technique are being used in addition to the 'prototype' technique described by Ayalon et al. (1975): (i) the classical technique, with an intended maximal frontal projection of the centre of gravity (CG), and (ii) a more recent technique, using a basic position characterised by a rear projection of the CG of the swimmer.

To our knowledge, the two variants have not yet been compared, although both were already compared with the most popular grab-start. Only one study compared the most recent variant with the grab-start (Juergens, 1994). Meanwhile, the more classic track-start was compared with the grab-start by several authors (Ayalon et al., 1975; Fitzgerald, 1973; Kirmer et al., 1989; LaRue, 1985; Shin and Groppel, 1986; Zatsiorsky et al., 1979). It was also compared with the conventional-start technique (Ayalon et al., 1975; Fitzgerald, 1973; Zatsiorsky et al., 1979).The purpose of this study was to describe and compare, using both kinematic and dynamic parameters, the two track-start techniques: the traditional track-start with the CG projected to the front (TSF), and the more recent track-start with the CG projected to the rear (TSR).

MATERIALS AND METHODS: Subjects were 11 males ranked as Portuguese top-level swimmers. All subjects came from the same club, and were previously trained for a period of one month in both of the two variants of the track-start (Shin and Groppel, 1986). The main characteristics of the subjects were: 8.36 (±2.20) years of age, 73.14 (±7.04) kg of mass, and 179.9 (±0.07) cm of height. Each swimmer performed three starts of each variant with a rest

period longer than 5 minutes. Starts were performed from a Bertec 4060 - 15 force plate that allowed a starting position conforming with swimming rules. The sampling rate was 1000Hz.
2D kinematics in the sagittal plane (lateral view) were assessed using the double camera set-up described previously by Vilas-Boas et al. (1997). Both cameras (JVC GR-SX1 SVHS-C PAL) were mounted over a specially designed support placed at the lateral wall of the pool, 3m from the edge of the pool deck. One camera was placed over-water, elevated 30cm above the water surface, and the other was kept underwater (IKELITE box) at a 30 cm depth, and exactly below the over-water camera. The optical axes were kept perpendicular to the axis of the swimmer's movement. Cameras were placed at 7m from the plane of movement. Images were mixed using a PANASONIC WJMX-50 mixing table with a separation line coincident with the water surface. Differences in light refraction were corrected using zoom and a dual media squared reference frame. Mixed images were recorded using a SVHS PANASONIC AG7350E VCR. This same VTR was also used for image processing procedure, allowing a sampling frequency of 50Hz. Images were processed using the Peak-5 system, from Peak Performance Technologies. Spatial model was composed by 20 anatomical landmarks digitised in each frame, defining a 14 body segments model. The anthropometric biomechanical model used was from Zatsiorsky adapted by de Leva (1996).
Starting signals conformed to the swimming rules and were produced through a starter device (ProStart). This device was instrumented to simultaneously produce the starting sound, and export a LED signal (duration higher than 0.1sec) to the video system, and a trigger signal to the A/D converter, allowing data synchronisation.
After filtering and smoothing, values obtained from force plate were the times, reaction forces and impulses, displacements and velocities of the CG. From videogrametry we obtained support, aerial, transitional and underwater kinematics of the CG. The end of the start was considered to be the horizontal coordinate of the last pixel visible (6.07m), which provided the same start length as the one studied by Lowell (1977).
The 27 biomechanical variables studied were: (i) reaction time (RT) - the time interval measured on the force plate between the start signal and the first perceptible movement; (ii) impulse time (IT) - the time interval measured on the force plate between the first perceptible movement and the take-off; (iii) block time (BT) - reaction time + impulse time; (iv) flight time (FT) - time from start to water touch minus the block time; (v) time from start to water touch (Ts-w) - measured by videogrametry from the starting signal to the moment of the first contact with the water; (vi) time from start to full water entry (Ts-e) - measured by videogrametry from the starting signal to the first moment of full water entry; (vii) total time of water entry (ET) - time from start to full water entry minus time from start to water touch; (viii) glide time (GT) - total start time minus time from start to full water entry (ix) total start time (TST) - measured by videogrametry from the start signal to the start end; (x) horizontal impulse (Ix) - measured by dynamometry by the product of the horizontal component of the block reaction force times the impulse time; (xi) vertical impulse (Iy) - measured by dynamometry by the product of the vertical component of the block reaction force times the impulse time; (xii) resultant impulse (Ir) - the resultant impulse of the vertical and horizontal components, computed based on the mean values of Ix and Iy; (xiii) limit horizontal velocity of the CG at the take-off (VxlimCGto) - measured by dynamometry in the last moment of contact of the feet with the force plate (dynamometric evaluation was computed based on horizontal impulse and swimmers' mass); (xiv) horizontal velocity of the CG at the take-off (VxCGto), measured by videogrametry in the last moment of contact of the feet with the force plate; (xv) vertical velocity of the CG at the take-off (VyCGto) - measured by videogrametry in the last moment of contact of the feet with the force plate; (xvi) horizontal velocity of the CG at the beginning of the water entry (VxCGbe) - measured by videogrametry immediately before water entry; (xvii) vertical velocity of the CG at the beginning of the water entry (VyCGbe) - measured by videogrametry immediately before water entry; (xviii) horizontal velocity of the CG at the end of the water entry (VxCGee) - measured by videogrametry immediately after water entry; (xix) vertical velocity of the CG at the end of the water entry (VyCGee) - measured by videogrametry immediately after water entry; (xx) horizontal velocity of the CG at the end of the start (VxCGES) - measured by videogrametry at the

horizontal coordinate of the last pixel visible (6.07m); (xxi) vertical velocity of the CG at the end of the start (VyCGES) - measured by videogrametry at the horizontal coordinate of the last pixel visible (6.07m); (xxii) total displacement of the CG during the period of block contact (TdCGbc) - measured by videogrametry during the period of contact of the swimmer with the force plate; (xxiii) total displacement of the CG during flight (TdCGfl) - measured by videogrametry between the loss of contact with the force plate and the first touch in the water; (xxiv) water reach of the CG in the moment of the first contact of the hands with the water (rCGw) - measured by videogrametry as the difference of horizontal coordinates of starting wall and the CG coordinates in the first contact of the hands with the water; (xxv) total displacement of the CG during water entry (TdCGe) - measured by videogrametry between the moment of water touch and the first moment of complete immersion; (xxvi) total displacement of the CG until start end (TdCGend) - measured by videogrametry from start signal to the horizontal coordinate of the last pixel visible (6.07m); (xxvii) angle of entry (ae) - measured by videogrametry between the trunk of the swimmer and the horizontal.
Data were treated using common descriptive statistics and one-way ANOVA ($\alpha = 0.05$).

RESULTS: The main results of the study are presented in Table 1. It can be noticed the two track-start techniques were significantly different in the following variables: (i) a higher impulse time for TSR than TSF; (ii) a higher block time for TSR and (iii) higher time durations from start to water touch and to full immersion. It can be assumed that all these differences were due to a longer block time.

Table 1 Main Dynamic and Kinematic Results Including Mean and Standard Deviations (SD) for TSR and TSF, F and p Values

Variables	TSR		TSF		ANOVA	
	Mean	SD	Mean	SD	F	p
TIME ANALYSIS:						
Reaction time (sec)	0.15	0.04	0.17	0.05	3.38	0.07
Impulse time (sec)	0.79	0.06	0.72	0.06	15.25	0.00*
Block time (sec)	0.94	0.07	0.90	0.07	5.53	0.02*
Flight time (sec)	0.36	0.06	0.34	0.05	1.36	0.25
Time from start to water touch (sec)	1.30	0.06	1.24	0.08	11.91	0.00*
Time from start to full water entry (sec)	1.63	0.07	1.59	0.08	5.36	0.02*
Total time of water entry (sec)	0.33	0.06	0.34	0.95	0.80	0.37
Glide time (sec)	0.75	0.16	0.82	0.22	2.09	0.15
Total start time - 6.07m - (sec)	2.39	0.17	2.41	0.24	0.22	0.64
DYNAMICAL ANALYSIS:						
Horizontal impulse (N sec)	245.48	30.37	227.99	30.37	5.39	0.02*
Vertical impulse (N sec)	578.82	73.06	525.15	66.02	9.67	0.00*
Resultant impulse (N sec)	628.72		572.50			
KINEMATICAL ANALYSIS:						
VxlimCG at take-off (m/sec) – Bertec	3.31	0.26	3.12	0.21	10.66	0.00*
VxCG at take-off (m/sec) - Peak-5	3.64	0.21	3.38	0.24	7.68	0.01*
VyCG at the take-off (m/sec)	0.15	0.31	0.31	0.36	3.51	0.07
VxCG at the beginning of entry (m/sec)	3.89	0.26	3.70	0.21	10.33	0.00*
VyCG at the beginning of entry (m/sec)	3.46	0.30	3.70	0.21	3.68	0.06
VxCG after water entry (m/sec)	3.28	0.43	3.21	0.22	0.59	0.44
VyCG after water entry (m/sec)	2.29	0.37	2.24	0.36	0.36	0.55
VxCG at the end of the start (m/sec)	1.81	0.29	1.79	0.32	0.10	0.75
VyCG at the end of the start (m/sec)	0.18	0.18	0.19	0.18	0.00	0.95
TdCG during block contact (m)	1.25	0.12	1.10	0.11	28.85	0.00*
TdCG during flight (m)	1.31	0.22	1.19	0.22	4.67	0.03*
Water reach of the CG at hands entry (m)	2.18	0.33	2.09	0.21	3.18	0.08
TdCG during water entry (m)	1.50	0.25	1.54	0.25	0.52	0.47
Total displacement of CG until start end (m)	5.82	0.11	5.86	0.13	22.95	0.00*
Angle of entry (°)	33.82	5.54	34.09	5.35	0.128	0.88

* differences statistically significant ($p<0.05$).

Considering the dynamic variables, it can be noticed that both horizontal and vertical impulses were higher for TSR than TSF. Consequently, the resultant impulse, computed over

the horizontal and vertical components, was also higher for TSR than TSF.
Horizontal CG velocities at the take-off, both evaluated from force plate and from the kinematical data processing system, were higher for TSR. Naturally, these observed differences on Vx at the take-off were also present at water entry. The only other kinematic variables that were different between the two techniques were: (i) total CG displacement during block contact; (ii) total CG displacement during flight and (iii) total CG displacement until start end.

DISCUSSION: Absolute values obtained in this study agree, in general, with previous literature. Ayalon et al. (1975) compared the track-start with three other start techniques. They found flight times between 0.4 and 0.5sec, block times of about 0.9sec, and a time to water entry between 1.15 and 1.25sec. Zatsiorsky et al. (1979) measured the total start time to a 5.5m distance over 45 subjects, using a special 'line system'. For the track-start (supposed TSF) they found 2.845 ±0.127sec, value corresponding to a lower velocity than the 2.39±0.17sec found in the present study for 6.07m. Differences may be attributed to the measurement device or to the performance level of the swimmers. These authors also found mean block times of 0.93±0.084sec, similar to the 0.90±0.07sec to 0.94±0.07sec that we found for the two variants of the track-start. Mean flight times of 0.387±0.065sec were also coherent with the 0.36±0.06sec and 0.34±0.05sec found here. Horizontal gliding velocities (1.64 to 2.97m/sec) were also similar to those we found (from 1.79 at the end point to 3.28m/sec just after entry), although this parameter is quite difficult to compare. Meanwhile, horizontal flight velocities found by Zatsiorsky et al. (1979) were higher than those that we found, probably due to supposed lower vertical velocities observed by the referred authors.
Shin and Groppel (1986) found, for the track-start (supposed TSF), a mean take-off time of 0.73sec, which is similar to the 0.72 (±0.06) sec that we found for TSF. From the contributions of these authors, we can also compare: (i) the distance from block to hip joint (2.67m) with the CG reach at water entry of the hands (2.09m); (ii) the mean time from start to water entry (1.18sec vs. 1.24sec), and the horizontal velocity of the hip joint (4.05m/sec) with the horizontal velocity of the CG (3.38 ±0.24m/sec at take-off, and 3.70 ±0.21 m/sec at water entry).
Kirner et al. (1989) presented values between 1.169sec and 1.255sec for time from starting signal to water entry in the track-start (supposed TSF), which are similar to the results found in this study (1.24 ±0.08sec). For the same authors, the entry angle was, for the track-start, about 39.89° (between 36.21° and 43.67°), slightly higher than the values that we obtained (33.82 ±5.54° for TSR, and 34.09 ±5.35° for TSF).
Juergens (1994) found block times for the TSR of 0.769 ±0.057sec, values higher than ours (0.94±0.07sec). He also found horizontal displacements of the CG (2.90 ±0.23m) slightly higher than the sum of our CG water reach (2.18 ±0.33m) and the backward placement of the CG in the initial position (0.32m).
Finally, dynamic data obtained by Juergens for the TSR were similar to those found in the present study. Juergens found values of the horizontal impulse of 269.8 ±43.9Ns, slightly higher than the 245.48 ±30.37Ns that we observed.
The results presented in Table 1 indicated that the main differences between the two track-start techniques seem to be related to the rear projection of the CG of the swimmer in one of the techniques.
This specific placement of the CG implies the body mass was accelerated through a greater distance after the start signal until take-off (higher total displacement of the CG during block contact), which explains the higher block time and impulse time observed for TSR, and also the longer duration from start to water touch.
Meanwhile, a longer distance of accelerating the body mass, and a higher impulse time are able to explain the higher impulses observed for the TSR, when compared with the TSF. These higher impulses are certainly the best explanation for the higher CG horizontal velocities at take-off and water entry. Higher impulses and take-off velocities can also explain total CG displacements during flight, which was found higher for TSR.
One very interesting finding of this study is that all the differences noticed among both track-

start techniques tended to disappear once immersion is completed, or, at least, once gliding in the water was performed. We can explain this effect accepting that higher velocities in water produce higher drag values, which caused greater deceleration of the bodies entering with higher speeds. This reduced the difference in gross performance parameters between the start techniques at the end.

CONCLUSIONS: From the presented data, it can be concluded that both track-start techniques seem to be equally valuable because all the differences noticed above water, vanished once the water glide took place. Until water touch, however, the TSF seems to be faster than the TSR, probably due to the lower time period spent in the starting block. The main differences noticed between the two track-start techniques seem to be related to the rear projection of the CG of the swimmer in the TSR.

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