Journal of Biomechanics 42 (2009) 1367–1370

Contents lists available at ScienceDirect

Journal of Biomechanics

journal homepage: www.elsevier.com/locate/jbiomech
www.JBiomech.com

Short communication

Analysis of swimmers' velocity during the underwater gliding motion following grab start

M. Elipot [a,c,*], P. Hellard [a], R. Taïar [b], E. Boissière [a], J.L. Rey [a], S. Lecat [a], N. Houel [a]

[a] Département Recherche Fédération Française de Natation, Pôle Natation INSEP, France
[b] Laboratoire d'Analyse des Contraintes Mécaniques, EA 3304 LRC-CEA, Université de Reims—UFR Sciences, France
[c] Laboratoire Ergonomie Comportement et Interactions, EA 4070-LAMA, Université Paris Descartes—UFR STAPS, France

ARTICLE INFO

Article history:
Accepted 5 March 2009

Keywords:
Swimming performance
Start
Underwater
3-Dimensional kinematical analysis

ABSTRACT

The purpose of this study was to determine the swimmers' loss of speed during the underwater gliding motion of a grab start. This study also set out to determine the kinematical variables influencing this loss of speed. Eight French national-level swimmers participated in this study. The swimmers were filmed using 4 mini-DV cameras during the entire underwater phase. Using the DLT technique and the Dempster's anthropometric data, swimmer's movement have been identified. Two principal components analysis (PCA) have been used to study the relations between the kinematical variables influencing the loss of speed. The swimmers reached a velocity between 2.2 and 1.9 m s^{-1} after their centre of mass covered a distance ranging between 5.63 and 6.01 m from the start wall. For this range of velocity, head position was included between 6.02 and 6.51 m. First PCA show that the kinematical parameters at the immersion (first image at which the swimmers' whole body was under water) are included in the first two components. Second PCA show that the knee, hip and shoulder angles can be included in the same component. The present study identified the optimal instant for initiating underwater leg movements after a grab start. This study also showed that the performance during the underwater gliding motion is determined as much by variables at the immersion as by the swimmer's loss of speed. It also seems that to hold the streamlined position the synergetic action of the knee, the hip and the shoulder is essential.

1. Introduction

In 50 and 100 m swimming races, performance has been strongly linked to start performance (Arellano et al., 1996; Mason and Cossor, 2000). Start performance is defined as the performance observed between the start signal and the moment when the swimmer's head reaches the 10th (Alves, 1993; Arellano et al., 1996) or the 15th meter (Issurin and Verbitsky, 2002; Mason and Cossor, 2000).

The start has three phases: the impulsion phase on the starting blocks (including the reaction time), the aerial phase and the underwater phase, including the glide phase and the underwater leg propulsion (Maglischo, 2003). Global analysis of starts has shown that the underwater phase of the start is decisive in order to achieve an efficient start (Clothier et al., 2000; Cossor and Mason, 2001; Shin and Groppel, 1986).

Studying the hydrodynamic resistance of 16 Australian elite swimmers, Lyttle et al. (2000) showed that the swimmers' propulsive movements should ideally be initiated when the underwater velocity reaches between 2.2 and 1.9 m s^{-1}. Nevertheless, swimmers rather estimate the optimal instant for initiating leg propulsion by using distance marks and speed information is less relevant to them.

Identifying the motor coordination is a decisive step to understand a movement (Alexandrov et al., 1996; Arellano et al., 2006; Ravn et al., 1999). To optimise the underwater gliding phase (i.e. to limit the swimmers' loss of speed), it seems important to identify the principal variables and the motor coordination influencing this phase of the start. Nevertheless, no study investigates those elements.

The aims of this study were: (1) to determine the swimmers' loss of speed during the underwater phase of a start and to estimate the distance between the swimmer and the start wall when swimmer's velocity decreases between 2.2 and 1.9 m s^{-1} and (2) to identify the factors and the motor coordination influencing this loss of speed.

2. Methods

2.1. Subjects and instructions

Eight swimmers, members of the French national team, participated in this study (Table 1). All subjects signed a consent form. All participants presented comparable 50 m freestyle levels of performance, height and weight to those who

* Corresponding author at: Département Recherche Fédération Française de Natation, Pôle Natation INSEP, 11 Avenue du Tremblay, 75012 Paris, France. Tel.: +33 6 10 32 06 75.
E-mail address: marc.elipot@voila.fr (M. Elipot).

0021-9290/$ - see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jbiomech.2009.03.032

took part in Lyttle et al.'s study (2000). The swimmers were asked to perform three grab starts as efficiently as possible. For each swimmer, only the best start has been analysed. Subjects practice this kind of start on a regular basis and use it for competition races. During the underwater phase of the start, the swimmers were to hold the streamlined position.

2.2. Experimental set up and data analysis

The underwater area covered by the cameras ranged from the start wall to the 15th meter (Fig. 1). This area was divided into three zones measuring $5 \times 2 \times 2$ m (length × width × weight): The first zone covered from the start wall to the 5th meter, the second zone from the 5th to the 10th meter and the third zone from the 10th meter to the 15th meter. Each zone was filmed by two mini-DV cameras (Fig. 1). To limit the effects of the image distortions on reconstruction accuracy at the border of the frame, only the points contained in the 2/3 centre of the camera field have been reconstructed. The cameras were positioned so as to minimize optical refraction effects (Kwon, 1999; Kwon and Casebolt, 2006): A large distance separated the cameras and the centre of each zone. The cameras' optical axes were perpendicular ($\pm 5^\circ$) to the air–water interface plane. The angles between the principal axis of the camera 1 and the other cameras were included between 55° and 70°. The overall space reconstruction and maximal reconstruction, calculated as described by Kwon and Casebolt (2006), were, respectively, 8.4 and 14.9 mm.

Sampling frequency was 25 Hz and the video has interlaced scan. Images have been deinterlaced and odd frames have been conserved. The entire underwater phase (from the instant at which the swimmers' whole body was under water, and until the swimmers stopped gliding or until their hands reached the surface) was filmed.

Nine anatomical landmarks have been chosen and identified (toes, lateral malleolus, knee, iliac spine, acromions, fingers' tip, wrist, elbow and centre of the head). To limit the errors during the digitizing process, this study assumes that both sides of the swimmer's body are symmetric. Only one side of the swimmers has been digitalized. Using the DLT method (Abdel-Aziz and Karara, 1971) and the Dempster's anthropometric data (Dempster et al., 1959), the trajectory of the centre of mass has been calculated. The best fit for this trajectory was determined using a polynomial method (order included between 7 and 9) (Tavernier et al., 1996; Winter, 1990).

During the whole underwater phase, the centre of mass velocity (V_X, V_Z and V_{2D}), the shoulder, the hip and the knee angles, and the slope of the V_X—distance curve (and the slope variation: SD_{slope}) have been identified.

The following parameters have been calculated at the first instant at which the swimmers' whole body was underwater (T_0): the centre of mass ($P_{(T_0)}$) and head ($H_{(T_0)}$) positions, the angle between the trunk and the water surface ($\alpha t_{(T_0)}$), and the centre of mass velocity ($V_{X(T_0)}$, $V_{Z(T_0)}$ and $V_{2D(T_0)}$).

2.3. Statistics

The principal components analysis (PCA) analysis is a useful tool to understand which groups of factors influencing a set of data (Alexander et al., 1996; Vernazza-Martin et al., 1999). In the present study, PCA allowed identifying the factors and the motor coordination influencing the distance at which the swimmer should initiate underwater leg propulsion.

A first PCA has been used to study the relations between the swimmers' loss of speed and the variables $V_{X(T_0)}$, $V_{Z(T_0)}$ and $V_{2D(T_0)}$, $P_{(T_0)}$, $\alpha t_{(T_0)}$ and SD_{slope}. A second PCA was applied to study the effect of shoulder, hip and knee angle's variations on swimmer's streamlined position. For each PCA, the mean eigenvalues have been calculated, expressed as a percentage of the results' variance explained and compared using an ANOVA (Tukey post-hoc test) ($p<0.05$).

3. Results

3.1. Initialisation of underwater leg's movement

Swimmers achieved an average V_X included between 2.2 and 1.9 m s^{-1} when their centre of mass had, respectively, covered a mean distance included between 5.63 m (SD = 0.51) to 6.01 m (SD = 0.60) from the start wall. Head position is included between 6.02 and 6.51 m (Fig. 2). Swimmers had to glide between 2.22 and 1.72 m.

3.2. Relation between kinematical variables at T_0 and the swimmer's loss of speed

The first two components explained, respectively, 53.94% and 31.94% of the results' variance (Fig. 3). The mean eigenvalues of those two components are significantly higher than the other component's eigenvalue.

Eigenvalues' analysis also allows classifying in the first component the variables $V_{X(T_0)}$, $V_{Z(T_0)}$, $V_{2D(T_0)}$ and SD_{slope}. Their eigenvalues are similar (Fig. 4). The second component includes the variables $P_{(T_0)}$ and $\alpha t_{(T_0)}$.

Table 1
Swimmers' general characteristics.

Height (m)		Body mass (kg)	Best performances (s): 50 m freestyle (s)	50 m freestyle (% of the world record)	100 m freestyle (s)	100 m freestyle (% of the world record)
Mean	1.85	78.5	24.41	114.7	51.84	109.1
SD	0.05	4.66	1.62	7.49	1.49	3.12

SD: standard deviation.

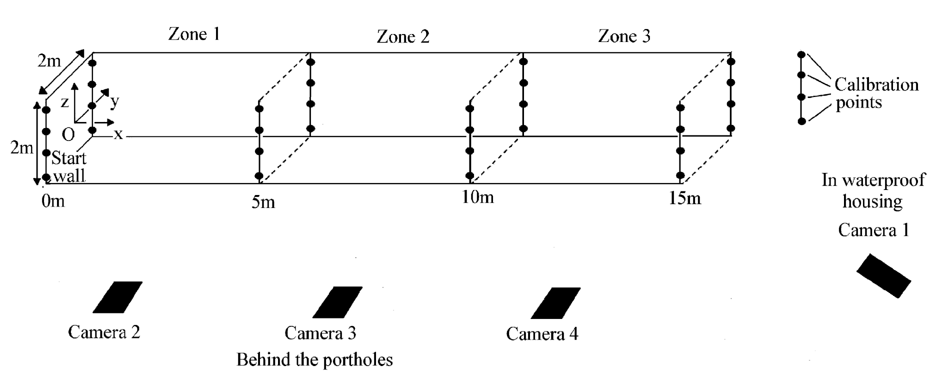

Fig. 1. Experimental set up and calibration points.