EFFECT OF FATIGUE ON KINEMATICS OF SPRINT UNDERWATER UNDULATORY SWIMMING

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The main aims of this study were to analyze body kinematics of underwater undulatory swimming and to determine the effect of fatigue along 15m. Performance of the undulatory underwater swimming decreased as distance increased, as it was showed by the higher values of the Strouhal number and the lower velocity at 12.5m distance. The swimmers were not able to maintain the high kick frequency from 7.5m to 12.5m and decreased their ankle angle which made the velocity decrease at 12.5m distance. In spite of the fact that the time per cycle was similar at both distances, the lower velocity produced lower cycle length at 12.5m Therefore, the swimmers covered longer distance per cycle at 7.5m.

KEYWORDS: Distance, performance, angular, kinematic, swimming, underwater undulatory.

INTRODUCTION: Underwater undulatory swimming (UUS) is the underwater movement that the swimmers make after the start and turns and is defined as the time between the first underwater kick and the first stroke (Elipot et al., 2009).

In the UUS, the kick cycle is divided in three parts: 1) the down-kick is characterized by a descendent movement from the highest up pike of the kick to the lowest down pike of the kick, 2) the first up-kick and 3) the second up-kick. 2) and 3) are the ascendant movements of the kick. The feet trajectory is more vertical in the first up-kick, while it turns more horizontal in the second up-kick (Arellano, Pardillo, & Gavilán, 2003).

An efficient UUS is characterized by a symmetric movement in which the swimmers must spend the same amount of time on the ascendant movement as on the descendent movement of each cycle (Atkinson, Dickey, Dragunas, & Nolte, 2014). Besides, the most efficient swimmers make a high volume of water rotate to start the up-kick and another small vortex is created to finish this phase (Arellano et al., 2003).

Many researchers have investigated the characteristics that UUS must have to reach high velocities: a reduction of the kick amplitude and an increase of the kick frequency combined with the increase of the knee angle (Arellano et al., 2003); a reduction of the angle of attack of the thigh and an increase of the angle of attack of the leg (Houel, Elipot, André, & Hellard, 2013); a reduction of the angle of attack of the arms due to high flexibility of the upper thorax, which will reduce the body undulations and the resistive drag (Atkinson et al., 2014); and good flexibility of the ankles to increase the propulsive force of the kick (Loebbecke, Mittal, Mark, & Hahn, 2009).

The UUS is the key element in the swimming performance and represents the fastest part of the race (Connaboy, Coleman, Moir, & Sanders, 2010). Swimmers may cover up to 15 m at the beginning of each lane (maximum distance permitted) using this technique, which may result in a long total distance per race. Therefore, the study of the UUS is of paramount importance to determine which technique can help swimmers avoid the large loss of velocity after the start and how this technique is affected by fatigue.

The main aims of this study were: a) to analyze body kinematics of UUS; b) to determine the effect of fatigue along 15 m. In order to do this, we investigated the behavior of kinematical parameters such as kick amplitude and frequency, kick horizontal displacement, average horizontal, vertical and resultant velocity of the hip and the center of mass (CM), feet angle of attack in the descendent and ascendant phase, and Strouhal number.

It was hypothesized that the fatigue will reduce the UUS performance obtaining worse results at a distance of 12.5m.

METHODS: Twenty-five swimmers of international level participated in this study (age: 23.04 ± 2.96 years; body mass: 71.94 ± 9.60 kg; height: 170.20 ± 8.18 cm). Each swimmer completed 15m of UUS after pushing from the wall at maximum velocity. UUS was measured at 7.5m and 12.5m distance from the wall where the swimmers began their displacement. Each trial was recorded by two cameras, positioned at 7.5m and 12.5m, perpendicular to the motion plane and 1 m depth on the lateral wall of the swimming pool, with shutter speed 1/500, 60 Hz and resolution 1280x720.

In order to apply the DLT 2D method a control object with dimensions of 2.80 x 1.92 m and 23 control points (calibration error of 0.65%) was used to calibrate the motion plane both at 7.5m and 12.5m distance.

Twelve anthropometrical points were used to define an 8-segment as it was suggested by Connaboy et al. (2010). The Center of Mass (CM) of each body segment was calculated using inertial properties (BSPs) such as mass, CM location and principal moments of inertia. The whole body CM was the sum of the CM of each segment body.

Kwon 3D software was used for digitization and the posterior kinematical analysis. All data were filtered with a Butterworth Low-Pass filter using a cut-off frequency of 6Hz.

Up-kick phase duration (UPD), down-kick phase duration (DPD), hip resultant velocity (VrH), hip horizontal velocity (VxH), horizontal velocity of the center of mass (VxCM), resultant velocity of the center of mass (VrCM), kick frequency, kick amplitude**,** kick length and Strouhal number were defined as kinematics variables. The angular variables were: up-kick knee angle (UKA), down-kick knee angle (DKA), up-kick ankle angle (UAKA), down-kick ankle angle (DAKA), up-kick shoulder angle (USA), down-kick shoulder angle (DSA), up-kick hip angle (UHA), down-kick hip angle (DHA). Figure 1 shows the definition of the angular variables.

Descriptive statistics were applied to calculate the mean and standard deviation for each variable. A paired t-test was used to examine the changes in variables between 7.5m and 12.5m. The Pearson correlation was used to observe the influence of the body position on the UUS performance.

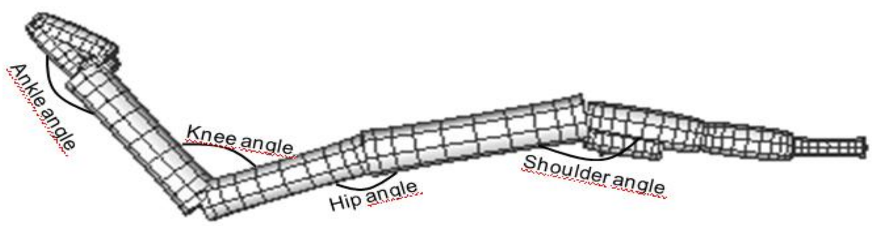

Figure 1: definition of the angular variables.

RESULTS: The differences between UUS at 7.5m and the UUS at 12.5m are showed in Table 1. The significant decrease of the resultant and horizontal velocity of the hip and the Center of Mass (CM) confirmed the loss of effectiveness of the UUS at 12.5m. Kick frequency, kick length and Strouhal number also changed significantly. In the angular variables significant differences were found in the up-kick and down-kick ankle angle and in the up-kick shoulder angle.

Table 1
Differences obtained between 7.5m distance and 12.5m distance

	7.5m	12.5m	p-value
UPD (s)	0.27 ± 0.07	0.27 ± 0.05	0.387
DPD (s)	0.20 ± 0.03	0.20 ± 0.03	0.896
VrH (m/s)	1.87 ± 0.27	1.67 ± 0.17	0.001*
VxH (m/s)	1.78 ± 0.23	1.70 ± 0.18	0.002*

VxCM (m/s)	1.79 ± 0.22	1.57 ± 0.18	0.001*
VrCM (m/s)	1.80 ± 0.23	1.57 ± 0.18	0.001*
Frequency (Hz)	2.12 ± 0.26	1.93 ± 0.50	0.041*
Amplitude (m)	0.57 ± 0.09	0.54 ± 0.08	0.098
Length (m/cycle)	0.85 ± 0.13	0.76 ± 0.07	0.001*
Strouhal	0.67 ± 0.05	0.71 ± 0.08	0.006*
UKA (°)	205.34 ± 5.06	204.36 ± 5.49	0.326
DKA (°)	212.81 ± 7.19	212.27 ± 4.95	0.675
UAKA (°)	170.88 ± 6.60	158.16 ± 9.82	0.001*
DAKA (°)	202.79 ± 8.48	186.78 ± 7.67	0.001*
USA (°)	171.28 ± 5.86	169.53 ± 5.99	0.049*
DSA (°)	170.82 ± 6.81	171.25 ± 6.21	0.592
UHA (°)	178.73 ± 4.47	180.48 ± 6.19	0.106
DHA (°)	157.54 ± 6.53	159.38 ± 7.43	0.123

DISCUSSION: The results obtained showed a similar duration of each phase at 7.5m distance and at 12.5m distance. However, the swimmers spend more time in the up-kick compared to the down-kick. These differences in the duration of each phase showed an asymmetry in the UUS. Atkinson et al. (2014) observed that faster UUS spend the same amount time in the up-kick phase that in the down-kick phase and therefore, with a symmetrical UUS the swimmers will improve their underwater phase.

The values of VrCM, VxCM, VrH and VxH decreased at 12.5m distance. Therefore, the velocity decreased with the increase of the distance.

Due to this decrease of the velocity values at the 12.5m distance and to the similar time spent per cycle, the swimmers obtained a lower length at this distance with respect to the 7.5m distance. Consequently, the swimmers covered a higher distance in the same lapse of time at the 7.5m distance.

The higher velocity values at the 7.5m distance were due to higher kick frequency. Shimojo et al. (2014) aimed to determine the influence of the frequency on the Strouhal number and the average velocity indicated that the swimmers should increase their frequency and maintain the amplitude constant. On the contrary, the swimmers would use a high propulsive force in order to increase their velocity, which would lead to fatigue.

In our results, we observed higher frequency and higher velocities at the 7.5m distance with respect to the 12.5m distance. In spite of the fact that the amplitude was constant at both distances, the swimmers could not maintain their kick frequency due to the fatigue. Therefore, the velocity decreased at the 12.5m distance.

According to the inverse relationship between the Strouhal number and the CM velocity (Arellano, Strouhal), the swimmers obtained higher velocities and lower values of the Strouhal number at 7.5m distance, leading to higher efficiency compared to the 12.5m distance. These results are in concordance with the results obtained by Gavilan et al. (2006).

Regarding the characteristics of the movement, the angular variables showed similar behaviour at the 7.5m and 12.5 m distances, except the ankle angle in the up-kick and down-kick and the shoulder angle in the up kick.

As indicated by Loebbecke et al. (2009), the higher propulsive force in the UUS is produced by a larger extension of the ankle. The ankle angle decreased at the 12.5m distance with respect to the 7.5m distance. Thus, the swimmers reduced their propulsive force at this distance and, consequently, their velocity.

CONCLUSIONS: The effect of fatigue on the UUS produces a loss of efficacy with the increase of distance. The swimmers decreased their efficiency and velocity at 12.5m distance due to a decrease of the kick frequency and a loss of propulsive force due to a lower ankle angle. In consequence, the swimmers were able to cover longer distance in the same lapse of time at 7.5m distance.

The swimmers are encouraged to train the UUS at maximum velocities aiming to maintain high kick frequencies, so that they can maintain the maximum performance until 15m.

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