INFLUENCE OF BODY POSITION ON DOLPHIN KICK KINEMATICS

Francisco Alves[1], Pedro Lopes[1], António Veloso[1], António Martins-Silva[2]

[1] Faculty of Human Kinetics, Technical University of Lisbon, Portugal
[2] Sports Department, University of Trás-os-Montes e Alto Douro, Portugal

In backstroke, butterfly and front crawl competitive swimming underwater glide after the starts and turns is followed by a series of dolphin kicks while the body is still completely submerged. The aim of this study was to analyze the kinematics of dolphin kick in three body positions, prone, dorsal and lateral. Six national level junior swimmers (17.02 ± 0.36 years) were filmed underwater after jumping from the start blocks in order to analyze 2 complete kick cycles at maximal velocity in each position (APAS). Lateral kicking showed lower frequency and higher feet, hip, elbow and hand transverse amplitude. Swimmers used higher ankle extension in the dorsal kick. Strouhal number (dorsal: 0.95±1.31; prone: 0.86±0.07; lateral: 0.95±0.83) were within the range of previous results for subelite swimmers but failed to discriminate body positions.

KEY WORDS: dolphin kick, body undulation, Strouhal number.

INTRODUCTION: The glide and underwater kick after diving into the water are important components of a swimming race. Underwater dolphin kicking in a prone position is used by many swimmers not only in butterfly races, but also in freestyle, for minimizing loss of velocity until the initiation of the stroke. Backstroke swimmers use dorsal dolphin kick as long as the present rules permit it, before returning to free swimming speed. Some competitors have also adopted a lateral streamline glide position followed by lateral dolphin kicking during freestyle races, in spite of lack of evidence of any advantage related to this choice (Maglischo, 2003).

Body displacements by using dolphin kick imply ondulatory movements with cephalo-caudal direction, as showed by Sanders et al (1995) for butterfly swimmers. The wave that travels caudally along the body during the stroke cycle can be described by low frequency waveforms dependent on the vertical displacement-time profiles of the body parts.

The Strouhal number, a dimensionless number which quantifies the frequency and spacing of vortex formation and defines an optimal range for thrust-inducing vortex formation, was related to a certain synchrony between stroke cycle frequency, peak-to-peak undulatory end-limb amplitude and mean swimming speed (Triantafyllou et al, 2000). An average Strouhal number in the range of 0.25 to 0.35 for maximum propulsive efficiency in fishes and aquatic mammals has been predicted by these authors.

Arellano et al (2002) compared the kinematics of underwater dolphin kick between two groups of different competitive level swimmers. Body velocity and stroke frequency were the main discriminative factors, inducing lower Strouhal numbers for the international level swimmers when compared to the less skilled swimmers (0.79 versus 0.95). Lyttle & Keys (2004), using numerical simulation by computational fluid dynamics, modelled the underwater dolphin kick of elite level swimmers in two types, large/slow and small/fast, differing in the combination of frequency and vertical amplitude of the feet and in some correlated angular characteristics of the lower limb movement. Strouhal numbers estimated were 0.57 and 0.52, respectively.

The aim of this study was to analyze the kinematics of dolphin kick in three body positions, prone, dorsal and lateral and compare its propulsive quality using the Strouhal number.

METHOD: Six junior national level swimmers volunteered for this study (age: 17.02 ± 0.36 years; height: 177.00 ± 3.58 cm; body mass: 69.25 ± 6.03 kg; best time at 100m butterfly long course: 59.85 ± 1.65 s). Each subject performed 3 x 25 m repeats with full rest, in a 50 m pool, at maximal velocity, after a start from the blocks. Oblique underwater front views from below and from both sides were taken by two fixed digital cameras (JVC 6800, 50 Hz, 1/250 of shutter speed), in underwater housings (Ikelite), covering the whole body for one complete stroke cycle. A set of lights were used for synchronizing the video recordings. Images from the 4th kick cycle were retained for 3D kinematical analysis (APAS).

A volume of 4.42 m in length, 1.41 m in width and 2.00 m in height was calibrated prior to the swimming trials by placing a control object with 30 points of known coordinates integrating the space swimmers would use for one complete stroke cycle. A global reference system was constructed. Eighteen body landmarks were manually digitised: vertex, chin-neck intersect, joint centers of shoulders, elbows, wrists, hips, knees and ankles, tip of the toes, tip of the fingers, corresponding to a 14-segment model of the human body. A digital filter (Butterworth) with a cut-off frequency of 5 to 8 Hz was used to smooth kinematic data. A complete stroke cycle was digitised. The identification of each of the two phases of the dolphin kick, the downsweep (DS) and the upsweep (US) was made from the underwater foot path. Absolute duration of each phase were calculated in milliseconds and expressed as a percentage of the duration of the total stroke cycle.

The Strouhal number, adapted for the study of the undulating swimmer, can be defined as: Strouhal number = Amp * *f* / Vs, where Amp is the distance travelled by the undulating limb extremity in the transverse plane, *f* is the stroke frequency and Vs is the intracycle average horizontal velocity of the centre of mass (Rohr & Fish, 2004).

All data are expressed as mean ± S.D. Differences between means were evaluated using a Wilcoxon test and correlations performed with the Spearman's rank order test. Vs was used as the dependent variable. Significance was set at p<0.05.

RESULTS: Although not significantly, lateral kicking displayed slower mean body velocities for the stroke cycle analyzed, as well as a lower movement frequency and a higher Strouhal number (Table 1). However, Vs difference during the US was significant, indicating this one to be a discriminating phase of the movement regarding variation of body position.

Table 1 Mean swim velocities, stroke frequency, and Strouhal Number for the three body positions. * p ≤ 0.05 between prone and lateral conditions

	Dorsal	Prone	Lateral
Vs ($m.s^{-1}$)	1.42 ± 0.21	1.46 ± 0.15	1.27 ± 0.11
Vs – US ($m.s^{-1}$)	1.40 ± 0.21	1.46 ± 0.14	1.23 ± 0.11*
Vs – DS ($m.s^{-1}$)	1.43 ± 0.21	1.46 ± 0.16	1.31 ± 0.12
f (Hz)	2.30 ± 0.33	2.35 ± 0.27	2.08 ± 0.36*
Strouhal number	0.95 ± 0.13	0.86 ± 0.07	0.95 ± 0.08

Lateral kicking showed more pronounced body transverse oscillations (Table 2), accompanied by more important knee flexion (Table 3) when compared to the other body positions, especially to prone kicking; prone kicking showed a rather stronger stabilization of the center of the mass. Dorsal kicking seems to stress the ankle joint imposing increasing values of maximal plantarflexion. Mean resultant foot acceleration decreased significantly during the US in all conditions and showed lower values during the lateral kicking than during the dorsal kicking (Table 4).

Curiously, Vs was not correlated between conditions. Main Vs influencing factors also varied: prone and dorsal kick Vs were both strongly associated to body mass; prone kicking Vs correlated significantly with *f* (r= 0.899, p=0.015), transverse elbow amplitude (r=-0.896, p=0.019) and foot resultant acceleration during the US (r= 0.943, p=0.005); lateral kicking Vs was poorly related to *f* (r= 0.812, p=0.05) but showed a high positive correlation with shoulder transverse amplitude (r= 0.886, p=0.019); dorsal kicking Vs was the only one to display a negative correlation with the Strouhal number (r= -0.886, p=0.019), due to a higher intragroup variation of this index.

Table 2 Vertical amplitude of selected body marks. * $p \leq 0.05$ between prone and lateral conditions; # $p \leq 0.05$ between dorsal and lateral conditions; + $p \leq 0.05$ among ventral, dorsal and lateral conditions

		Dorsal	Prone	Lateral
Transverse amplitude (m)	**Foot (toes)**	0.55 ± 0.08	0.50 ± 0.06	0.59 ± 0.09
	Ankle	0.37 ± 0.05	0.34 ± 0.05	0.46 ± 0.07 *#
	Knee	0.24 ± 0.03	0.21 ± 0.03	0.28 ± 0.02 *
	Hip	0.12 ± 0.03	0.12 ± 0.01	0.16 ± 0.02 *
	Shoulder	0.06 ± 0.02	0.07 ± 0.01	0.09 ± 0.03 #
	Elbow	0.06 ± 0.01	0.05 ± 0.02	0.09 ± 0.02 *#
	Wrist	0.07 ± 0.08	0.07 ± 0.03	0.11 ± 0.02 #
	Hand	0.08 ± 0.02	0.11 ± 0.04	0.13 ± 0.03 #
	Head	0.06 ± 0.01	0.07 ± 0.02	0.08 ± 0.03
	Center of mass	0.05 ± 0.01	0.03 ± 0.01	0.08 ± 0.01 +

Table 3 Foot resultant velocity and acceleration during the whole cycle and during each phase: upsweep (US) and downsweep (DS). * $p \leq 0.05$ between prone and lateral conditions; + $p \leq 0.05$ among ventral, dorsal and lateral conditions

		Dorsal	Prone	Lateral
Peak joint angles (^{o})	Ankle plantarflexion	173.87 ± 3.51	168.93 ± 3.80	162.96 ± 5.76 +
	Knee flexion	120.72 ± 13.05	119.34 ± 3.70	107.73 ± 8.68 *

Table 4 Foot resultant velocity and acceleration during the whole cycle and during each phase: upsweep (US) and downsweep (DS). # $p \leq 0.05$ between dorsal and lateral conditions

		Dorsal	Prone	Lateral
Resultant Velocity (m.s^{-1})	Whole Cycle	3.14 ± 0.17	3.19 ± 0.28	2.91 ± 0.17 #
	US	3.26 ± 0.20	3.32 ± 0.39	2.98 ± 0.24
	DS	3.01 ± 0.26	3.06 ± 0.22	2.86 ± 0.17
Resultant Acceleration (m.s^{-2})	Whole Cycle	39.41 ± 4.82	41.39 ± 8.20	38.10 ± 5.72
	US	36.32 ± 2.43	36.99 ± 10.76	29.29 ± 6.04 #
	DS	45.94 ± 7.99	50.40 ± 5.09	47.08 ± 7.63

DISCUSSION: The present study investigated the underwater undulation motion performed by swimmers after the initial glide following the dive into the water, aiming to uncover the influence of body position on selected kinematic parameters.

Dorsal kicking seems to be accompanied by more important vertical oscillations of the body than prone kicking, confirming the results of Arellano (1999). Significant differences in kinematical characteristics were also found between the prone and the lateral dolphin kicks for an almost identical velocity. Higher maximal knee flexion and transverse oscillations of the ankle, knee, hip and elbow, together with lower *f* seems to indicate a less efficient movement pattern. This may be due to less familiarization with this movement variant since the swimmers of this study neither used lateral kicking in competitive situations nor trained it frequently at high intensities.

Triantafyllou et al. (1993) showed that a variety of fish and cetaceans swim with a frequency and amplitude of tail motion that are within a narrow range of Strouhal numbers, minimizing energy lost in the wake for a given momentum and increasing efficiency. This Strouhal number range corresponds to the regime of maximum stability of the vortex wake thrust jet.

In finswimming, Nicolas et al (2003) found values for the Strouhal number in the range of 0.35 to 0.68. The swimmers in this study showed poor balance between foot transverse amplitude and stroke frequency for the swim velocities evaluated, when compared to the optimized values predicted by Lyttle & Keys (2004).

The range of values found for prone dolphin kicking (0.79 to 0.98) is within what has been described for competitive swimmers (Arellano et al, 2002), but the lowest value (0.78) was displayed in the dorsal position. Observation of individual results permitted us to verify that the lower Strouhal numbers were found in the faster swimmers in all conditions, in spite of a lack of correlation between this index and Vs in prone and lateral positions. The values were nonetheless rather homogeneous in the former condition. On the other hand, the highest Strouhal numbers were achieved by swimmers with wider transverse amplitudes.

REFERENCES:

Arellano, R. (1999). Vortices and propulsion. In R. Sanders & J. Linsten (Eds.), Swimming: Applied Proceedings of the XVII International Symposium on Biomechanics in Sports Vol. 1 (pp 53-66). Perth, Western Australia: School of Biomechanics and Sports Science.

Arellano, R., Pardillo, S. & Gavilán, A. (2002). Usefulness of the Strouhal Number in evaluating human underwater undulatory swimming. In J. Chatard (Ed.), Biomechanics and Medicine in Swimming IX (pp 213-218). Saint-Etienne: Publications de l'Université de Saint-Étienne.

Gautier, J., Baly, L., Zanone P.-G. & Watier, B. (2004). A kinematic study of finswimming at surface. Journal of Sports Science and Medicine, 3, 91-95

Lyttle, A. & Keys, M. (2004). The use of computational fluids dynamics to optimize underwater kicking performance. In M. Lamontagne, D.G.E. Robertson & H. Sveistrup (Eds.), Proceedings of the XXIInd International Symposium on Biomechanics in Sports - ISBS 2004 (pp 438-441). Ottawa: Faculty of Health Sciences, University of Ottawa.

Lyttle, A.D. & Mason, B. (1996). A kinematic and kinetic analysis of the freestyle and butterfly. Journal of Swimming Research, 12, 7-11.

Maglischo, E.W (2003). Swimming fastest. Champaign: Human Kinetics.

Nicolas, G., Colobert, B., Bideau B., Fusco N. & Delamarche P. (2003). Nombre de Strouhal et resistance active en nage avec palme. In P. Pelayo (Ed.), Actes des 3èmes journées spécialisées de natation (pp 153-155). Paris: Publibook.

Read, D.A., Hover, F.S. & Triantafyllou, M.S. (2003). Forces on oscillating foils for propulsion and maneuvering. Journal of Fluids and Structures, 17, 163–183.

Rohr, J.J. & Fish, F.E. (2004). Strouhal numbers and optimization of swimming by odontocete cetaceans. Journal of Experimental Biology, 207(Pt 10),1633-42.

Sanders, R.H., Cappaert, J. & Devlin, R. (1995). The wave characteristics of butterfly swimming. Journal of Biomechanics, 28 (1), 9-16.

Triantafyllou, G.S., Triantafyllou, M.S. & Grosenbaugh, M.A. (1993). Optimal thrust development in oscillating foils with application to fish propulsion. Journal of Fluids and Structures, 7, 205–224.

Triantafyllou, M.S., Triantafyllou, G.S. & Yue, D.K.P. (2000). Hydrodynamics of fishlike swimming. Annual Revue Fluid Mechanics, 32, 33-53.