LINEAR KINEMATICS OF THE UNDERWATER UNDULATORY SWIMMING PHASE PERFORMED AFTER TWO BACKSTROKE STARTING TECHNIQUES

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The purpose of this study was to analyze the effects on relevant kinematic parameters of the underwater undulatory swimming (UUS) phase of the repetition of these UUS cycles and of the starting technique used: the one with the feet parallel and entirely immerged (BSFI) and the other with the feet parallel and entirely emerged (BSFE). Four high level swimmers performed 3x15 m maximal sprints using each technique (BSFI and BSFE). In both starting techniques the mean horizontal velocity and horizontal amplitude were greater for the 4 initial UUS cycles than the last 4 ones. At BSFI, the 4 initial UUS cycles showed greater mean frequency than the last 4 ones. No differences were observed between BSFI and BSFE for the 4 initial UUS cycles. Coaches should consider the frequency of UUS cycles to optimize underwater phase performance at BSFI and BSFE.

KEY WORDS: biomechanics, velocimetry, dolphin kick, performance.

INTRODUCTION: The swimming start (SS) phase is commonly defined as the actions performed until the completion of the first 15 m mark of the race, and it is the maximum distance a swimmer can travel underwater, as per the FINA rules. The SS can be divided into a number of subsections including block/wall, flight, entry, underwater and free swimming phases (Burkett, Mellifont &Mason, 2010). The underwater phase of the start could be divided into 2 phases, the glide and the underwater undulatory swimming (UUS) phases (Elipot, Houel, Hellard, Dietrich, 2010). During the UUS the body assumes a streamlined body position with the arms outstretched beyond the top of the head and the hands placed one over the other. Displacements of the body segments are normal to the coronal or transverse anatomical plane and have minimum magnitude at the hands, and increase along the length of the body, reaching a maximum at the toes (von Loebbecke, Mittal, Fish & Mark, 2009).
The findings to date have emphasized that great consideration should be given to the UUS performance, as Guimarães & Hay (1985) showed that 95% of the variance in the start time was due to the underwater phase. Therefore it is imperative that swimmers maximizes velocity at the start and keep this velocity for as high and as long as possible (Burkett et al., 2010). Despite the recognition of the relevance of the UUS to optimize SS performance, little is known about technical modifications during the UUS cycles, particularly when performing two currently used starting techniques for backstroke events: one with the feet parallel and entirely immerged (BSFI), and one other with the feet parallel and entirely above the water surface (BSFE). The present study aimed to analyze the effects on relevant kinematic parameters of the underwater undulatory swimming phase of the repetition of the undulated underwater swimming cycles and of the starting technique used: the one with the feet parallel and entirely immerged and the other with the feet parallel and entirely emerged.

METHODS: Four high level swimmers (age: 22.75 ± 1.70 yrs, body mass: 75.95 ± 8.85 kg, height: 1.78 ± 0.06 m; best performance over 100 m backstroke: 56.91 ± 2.29 s and 93.20 ± 3.72 % of the world record at that time) performed two randomized sets of three maximal bouts of 15 m backstroke starting technique with feet totally immerged and emerged, both variants with feet parallel to each other. Rest periods of 2 min and 1 h were provided between bouts and sets, respectively. A cable velocimeter (Lima, Capitão, Morouço, Gonçalves, Fernandes, Barbosa, Correia, Tani & Vilas-Boas, 2006) with a sampling rate of 50Hz connected at the distal end to a harness belt attached to the swimmer´s waist was used to assess linear kinematic parameters of successive UUS cycles (upward and downward kick) (Figure 1).

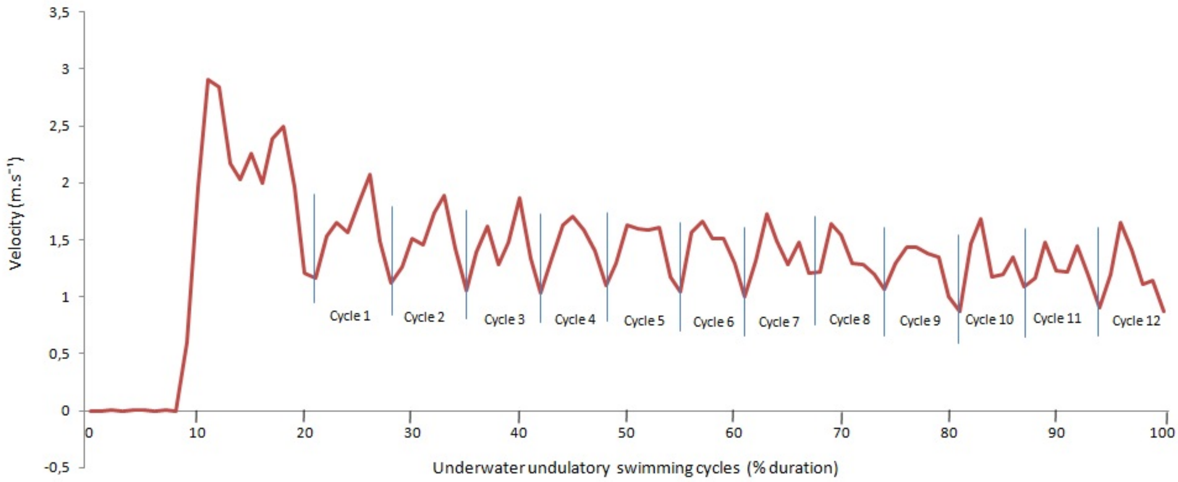

Figure 1: Individual example of the linear velocity of the fixed point (hip) time curve for backstroke start variant with feet parallel and immerged. Vertical lines distinguish the 12 UUS cycles.

The kinematical analysis of the four initial and the last four UUS cycles was performed using a MatLab routine, which include a correction for the effect of the cable angulation. Five horizontal linear kinematic parameters were determined in each individual velocity to time curve and presented as a mean value of each of the groups of four UUS cycles: (i) mean horizontal velocity (v4), computed directly from the acquired velocity data; (ii) time to complete one UUS cycle (t4); (iii) horizontal amplitude(ha4), computed as time integral of the velocity curve in each UUS cycle; (iv) horizontal acceleration (ac4), computed as the time differentiation of the velocity curve during the UUS cycle; (v) frequency (fc4), computed as one cycle divided by the duration of this cycle. The corresponding hip velocity-time curves were filtered with a low pass Butterworth filter with cut off frequency set at 10Hz. A starting device was programmed to produce the starting signal. Velocimetric data output was backwards synchronized with video images from the instant of take-off. After the normality of the distributions was confirmed (Shapiro-Wilk test), a paired sample *t*-test was used to assess statistical differences between linear kinematic parameters of the 4 initial and the last 4 UUS cycles for BSFI and BSFE, and between the linear kinematic parameter of the BSFI and BSFE for the 4 initial UUS cycles. Confidence level of $P < 0.05$ was accepted as significant. The effect size (*d*) for each variable was calculated in accordance with Cohen (1988) to measure the magnitude of difference. The criteria for interpreting the absolute effect size were based on Cohen's (1988) suggestion that effect sizes of 0.2 are small, 0.5 moderate, and 0.8 large.

RESULTS: Table 1 presents the means ± sd and effect sizes for the horizontal linear kinematic variables studied (v4, t4, ha4, ac4, and fc4) for the 4 initial and the last 4 UUS cycles both for the BSFI and BSFE. The 4 initial UUS cycles showed greater v4 than the last 4 ones for BSFI and BSFE, with large effect sizes. At BSFI, t4 was lower for the 4 initial UUS than the last four ones. In both backstroke start variants the ha4 presented greater value for the 4 initial than the last 4 UUS cycles. Analyzing the ac4, no differences were observed for the two backstroke start variants. The 4 initial UUS cycles presented a greater fc4 than the last 4 ones for BSFI, with a large effect size.
None of the horizontal linear kinematic variables were different between the BSFI and BSFE for the 4 initial and the last 4 UUS cycles.

Table 1: Means ± sd and effect sizes for the horizontal linear kinematic variables studied (v4, t4, ha4, ac4, and fc4) for the 4 initial and the last 4 UUS cycles, both for the backstroke starting techniques with the feet parallel and entirely immerged (BSFI) and with the feet parallel and entirely emerged (BSFE).

Variables	Variants	4 initial UUS cycles	4 end UUS cycles	*P*-value	Effect size (*d*)
v4 ($m.s^{-1}$)	BSFI	†1.47 ± 0.11	1.28 ± 0.07	< .001	0.87
	BSFE	1.44 ± 0.04	1.30 ± 0.04	< .001	0.83
t4 (s)	BSFI	0.41 ± 0.02	0.43 ± 0.03	0.02	-0.76
	BSFE	0.41 ± 0.03	0.42 ± 0.04	0.49	-0.21
ha4 (m)	BSFI	0.61 ± 0.07	0.55 ± 0.05	.001	1.37
	BSFE	0.60 ± 0.06	0.55 ± 0.07	.018	0.79
ac4 ($m.s^2$)	BSFI	-0.02 ± 0.09	ǂ-0.02 ± 0.07	0.95	0.07
	BSFE	-0.02 ± 0.04	-0.01 ± 0.05	0.79	0.09
fc4 (Hz)	BSFI	2.42 ± 0.15	2.33 ± 0.19	0.02	0.72
	BSFE	2.41 ± 0.20	2.39 ± 0.24	0.57	0.18

DISCUSSION:

The UUS in competitive swimming is typically used following water entry during a SS, as well as after turns in freestyle, backstroke and butterfly, allowing sustaining the much higher swimming velocities characteristic of these phases until surface is reached and free-swimming begins (von Loebbecke et al., 2009). As a consequence, it is expected that, at least, velocity drops from the first 4 to the last 4 UUS cycles. Accordingly, the aim of the present study was to kinematically compare these groups of UUS cycles within and between two backstroke starting techniques (BSFI and BSFE). Looking at the effects of the group of UUS cycles on the v4, it was observed, as expected, a greater value for the 4 initial UUS cycles in both backstroke start techniques. This might be due to a fatigue effect but most probably because swimmers started kicking before the maximal UUS velocity was reached. One other possible explanation is that drag increases when the swimmer approaches the water surface at the end of the UUS, due to an increased wave drag effect (Sanders & Byatt-Smith, 2000; von Loebbecke et al., 2009). A propulsion lost may also be associated to the observed fc4 reduction between the first and last group of 4 UUS cycles, once kicking frequency may be associated to vortex generation and propulsion. Indeed, von Loebbecke et al. (2009) observed that frequency of the UUS cycles are of particular importance in determining propulsive performance, despite authors reported that the kick frequency was not correlated with swimming velocity. In fact, to achieve the best performance during the UUS phase, the swimmers have to find the optimal compromise between propulsion force generation and reduction of the hydrodynamic drag (Elipot et al., 2010). Accordingly, at BSFI, it was noted that t4 was lower and fc4 higher for the 4 initial UUS cycles than the last 4 ones. A similar tendency (not significant) was also noted for BSFE. This fact might be associated with a speculated increase of leg amplitude to create a bigger wake of counter-rotation vortices and maximize the propulsion at the end of UUS (Elipot et al., 2010), in an effort to increase propulsion to compensate the increased drag. Despite the reduced t4, the much higher v4 values for the first 4 cycles allowed higher ha4 values, for the 4 initial UUS cycles. Accepting that the water depth seems to have a positive effect in reducing hydrodynamic drag during underwater phase (von Loebbecke et al., 2009), swimmers undulating near the water surface at the last 4 UUS cycles might compromise the horizontal amplitude, although maintaining a constant ac4 between the initial and last 4 UUS cycles.

Results showed no differences between the two studied starting techniques in what concerns the linear kinematic parameters of the four initial and last four UUS cycles, which means that swimmers adopted similar technical underwater strategies to achieve UUS velocities as higher as possible, independently of the constrains imposed by the feet positioning during the wall phase. Indeed, Vilas-Boas, Cruz, Sousa, Conceição, Fernandes & Carvalho (2003) showed, for ventral start techniques, that the underwater phase can compensate the differences produced during the impulse and flight phases between starting techniques. Despite not significant in statistical terms, a tendency to attain lower initial underwater velocities was perceived for the BSFE (-0.03m/s – meaning a loss of 3 cm in one second).

This might be related to the flattest trajectory of the centre of mass at BSFE during the flight phase compared to BSFI (de Jesus, de Jesus, Figueiredo, Gonçalves, Pereira, Vilas-Boas & Fernandes, 2010), which might determine a drag increase during water entry. In fact, Elipot et al. (2010) noted that the velocities during the UUS phase were not only due to the leg action but also a result of the velocities created during the impulsion and aerial phases.

CONCLUSION: Differences in kinematical parameters between the underwater undulation phase following both backstroke starting techniques were not observed. However the first four undulating kicking cycles differed from the last four cycles performed before the 15 m mark. In both backstroke start techniques it was observed that swimmers decrease v4 and ha4, and tended to increase t4 and reduce fc4 at the 4 last UUS cycles compared to the 4 initial ones. In terms of technique development, coaches should instruct swimmers to maintain greater frequency of UUS cycles especially when swimming near the water surface to achieve top velocity.

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