HYDRODYNAMIC ANGLES, ORIENTATION AND VELOCITY OF THE HAND IN FRONT CRAWL SWIMMING

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The hydrodynamic parameters of the hand (angle of attack, sweepback, velocity and orientation) play an important role in the generation of the resultant forces. These parameters were measured throughout an aquatic stroke to study the possible modifications caused by a variation of the swimming pace. Seventeen competitive swimmers swam at the long distance, middle distance and sprint paces. Parameters were calculated from the trajectory of seven markers on the hand measured with an optoelectronic system. Results showed that sweepback and angle of attack, and orientation of the hand do not vary significantly depending to the pace. Only the velocity of the hand increases when the pace increases, but only during the less propulsive phases. The increase of pace is then explained by the swimmer's capacity to maintain propulsive phases rather than increasing the force generation within each cycle.

KEY WORDS: angle of attack, sweepback angle, optoelectronic system.

INTRODUCTION: Propulsion in front crawl swimming is mainly provided by the upper limbs and in particular the hands (Maglischo, 2003). The flow around the hand is the cause of the generation of the forces. This flow depends of the hand kinematic, which can be defined from four hydrodynamic parameters: sweepback and angle of attack, velocity and orientation of the hand. The sweepback angle defines the leading edge of the hand relative to the water flow (Schleihauf, Gray & DeRose, 1983). The angle of attack (preferred over pitch term) defines the angle between the hand plane and the flow (Schleihauf et al., 1983; Gourgoulis et al., 2010). The velocity of the hand is defined as the mean of the resultant velocities of the 2nd and the 5th metacarpophalangeal joints. The orientation of the hand will be defined from three Euler angles (flexion, rotation and abduction) that will locate the hand relative to the absolute referential.
Many studies have shown that the basic kinematic parameters (SL, SF, velocity of the swimmer) evolved when the pace increased while swimming, but what about these hydrodynamic parameters? The purpose of the present research is to investigate the evolution of hydrodynamic parameters over time, on a significant population of competitive swimmers. To answer these questions, we measured the hydrodynamic parameters from an optoelectronic system, from national and regional level swimmers, at the characteristic paces of competitive swimming: long distance, middle distance and sprint.

METHODS: Seventeen swimmers (nine men and eight women) participated in this study. (Height: 1.76 ± 0.07 m; Mass: 69.6 ± 10.7 kg; Age: 20.4 ± 2.1 years; Level: 83.8 ± 3.4 % world record). All participants (or their parents) provided written consent prior to their participation. The test procedures were approved by the university ethics committee.
Experimentations were conducted in a specific pool of an Institute of research. Swimmers were asked to perform three trials at the three characteristic paces of swimming: sprint (corresponding to 50m and 100m distances), middle distance (200m and 400m) and long distance (800m and 1500m). Velocity was measured to validate the requested swimming pace using a chronometer. An aquatic stroke begins when the hand enters into the water and finishes when it exits.

All the aquatic measurements were recorded from an optoelectronic system composed of eight Vicon T-40 cameras (Monnet, Samson, Bernard, David & Lacouture, 2014). Five markers (diameter 14 mm) were fixed on the right hand (FT, M5, M2, M5i and M2i) and two markers were fixed on the wrist at the radial styloid RS and ulnar styloid US.
Sweepback and angle of attack were calculated from four anatomical landmarks: wrist center (middle of the [RS, US] segment), tip of the third finger (FT), second (M2) and fifth (M5) metacarpophalangeal joints. The angle of attack was determined as the angle between the velocity vector of the hand and its projection onto the plane of the hand (Gourgoulis, 2010). Sweepback angle was determined as the angle between the projection of the velocity vector onto the plane of the hand and the Yh-axis of the hand reference system (Xh, Yh, Zh). This hand reference system, linked to the hand-forearm, has been defined as: Xh was the axis which passed through FT and the middle [RS, US]. Yh was perpendicular to Xh and passed through (M5, M2) and Zh was perpendicular to the Xh-Yh plane. The orientation of the hand was obtained by decomposing the relative orientation relative to the absolute reference (X, Y, Z) and using appropriate sequences of Euler angles: flexion, rotation and abduction. The orthogonal reference system (X, Y, Z) is defined with the X-axis points in the swimming direction, the Y-axis is perpendicular to the swimming direction pointing from the right to the left of the participant, and the Z-axis points vertically upward. The aquatic stroke was decomposed in five phases Maglischo (2003): entry and stretch (ES, from entry of the hand into the water to the exit of water of the opposite arm); downsweep to catch (DC, from the end of ES to the outermost lateral point); insweep (IN, from the end of DC to the innermost point); upsweep (UP, from the end of IN to the rearmost point); and, exit (EX, from the end of UP to the exit of water).
Repeated-measures analysis of variance, completed with the pair-wise multiple comparisons Bonferroni test, were used for the statistical treatment of the data. Each phase was treated separately. The assumption of normally distributed samples and the sphericity were verified using the Kolmogorov-Smirnov test and the Mauchly test, respectively. Statistical significance was set at $P<0.05$.

RESULTS: The different parameters were calculated from the measures of the trajectory of the markers, and are shown in the Table 1. The uncertainty of measured is 2 degrees for the angles, and 0.05 $m.s^{-1}$ for the velocity.

Table 1
Mean (± SD) of kinematic and hydrodynamic paramaters and orientation of the hand, at the three paces of swimming, for the different phases oft the arm stroke. LD: long distance; MD: middle distance; S: sprint.

a- Kinematic parameters

	Absolute duration (s)					Hand velocity (m/s)				
	LD	MD	S	*F-value*	*P- value*	LD	MD	S	*F- value*	*P- value*
ES	**0.34** ± *0.06*	**0.28** ± *0.05*	**0.20** ± *0.04*	*28*	***0.00****	**1.86** ± *0.18*	**1.95** ± *0.19*	**2.21** ± *0.22*	***13.49***	***0.00****
DC	**0.40** ± *0.08*	**0.34** ± *0.07*	**0.26** ± *0.06*	*8.29*	***0.00****	**1.74** ± *0.25*	**1.83** ± *0.25*	**2.06** ± *0.26*	***8.23***	***0.00****
IN	**0.20** ± *0.10*	**0.19** ± *0.09*	**0.19** ± *0.08*	*0.16*	*0.85*	**2.15** ± *0.27*	**2.14** ± *0.24*	**2.19** ± *0.22*	*0.17*	*0.84*
UP	**0.17** ± *0.09*	**0.17** ± *0.08*	**0.17** ± *0.09*	*0.17*	*0.84*	**2.54** ± *0.32*	**2.59** ± *0.29*	**2.78** ± *0.36*	*2.60*	*0.08*
EX	**0.09** ± *0.10*	**0.08** ± *0.10*	**0.06** ± *0.08*	*2.16*	*0.13*	**2.59** ± *0.23*	**2.78** ± *0.36*	**3.03** ± *0.28*	***7.92***	***0.00****

b- Hydrodynamic angles

	Angle of attack (Deg)					Sweepback angle (Deg)				
	LD	MD	S	*F-value*	*P- value*	LD	MD	S	*F- value*	*P- value*
ES	**7** ± *5.8*	**11** ± *8.2*	**14** ± *7.6*	*3.10*	*0.06*	**71** ± *11.9*	**71** ± *8.7*	**75** ± *11.7*	*0.52*	*0.60*
DC	**30** ± *12.1*	**32** ± *10.3*	**34** ± *7.1*	*0.63*	*0.54*	**67** ± *17.6*	**61** ± *15.6*	**63** ± *18.9*	*0.66*	*0.52*
IN	**64** ± *8.9*	**65** ± *8.3*	**63** ± *7.3*	*0.25*	*0.78*	**188** ± *36*	**183** ± *33.6*	**190** ± *41*	*0.16*	*0.85*
UP	**43** ± *7.1*	**42** ± *7.4*	**37** ± *6.7*	*2.95*	*0.06*	**295** ± *11.9*	**292** ± *11.8*	**293** ± *11.6*	*0.21*	*0.81*
EX	**25** ± *8.7*	**22** ± *7.9*	**19** ± *6.5*	*1.12*	*0.34*	**299** ± *8.2*	**298** ± *7.1*	**296** ± *8.8*	*0.34*	*0.72*

c- Orientation of the hand

	Flexion (Deg)					Rotation (Deg)				
	LD	MD	S	F-value	P- value	LD	MD	S	F- value	P- value
ES	**9** ± *8.2*	**8** ± *9.2*	**17** ± *9.8*	***4.14***	***0.02****	**-4** ± *18.1*	**-6** ± *17.1*	**-8** ± *18.8*	*0.15*	*0.86*
DC	**31** ± *9.1*	**33** ± *8.2*	**36** ± *9.5*	*2.00*	*0.15*	**2** ± *11.9*	**-1** ± *12.5*	**0** ± *13.8*	*0.20*	*0.82*
IN	**86** ± *11.5*	**83** ± *12.4*	**82** ± *15.4*	*0.44*	*0.65*	**16** ± *9.2*	**16** ± *8.5*	**17** ± *9.3*	*0.07*	*0.93*
UP	**117** ± *14*	**114** ± *14.9*	**112** ± *16*	*0.47*	*0.63*	**18** ± *12*	**18** ± *11.9*	**21** ± *12.3*	*0.22*	*0.80*
EX	**138** ± *12*	**135** ± *18.2*	**141** ± *17.9*	*0.40*	*0.67*	**39** ± *14.4*	**40** ± *20.3*	**46** ± *27.8*	*0.38*	*0.69*

	Abduction (Deg)				
	LD	MD	S	F- value	P- value
ES	**14** ± *18.3*	**13** ± *20.3*	**5** ± *27.8*	*1.91*	*0.16*
DC	**7** ± *14.3*	**7** ± *11*	**3** ± *13.1*	*0.71*	*0.50*
IN	**17** ± *11.2*	**18** ± *9.8*	**15** ± *10.8*	*0.20*	*0.82*
UP	**2** ± *10.6*	**0** ± *11.2*	**12** ± *11.1*	*1.53*	*0.23*
EX	-	-	-	-	-

The more the pace increases, the more the absolute duration of the ES and DC phases decreases (Table 1a). Absolute duration of IN, UP and EX do not significant vary.
For all the phases, the more the pace increases, the more the hand velocity increases (Table 1a). But there are not significant differences between the phases in the velocity during the IN and UP phases. There are significant only during the ES, DC and EX phases. For the angle of attack, the highest data occur during the phase of insweep: 64° for the long distance, 65° for the middle distance and 63° for the sprint (Table 1b). During the upsweep phase, the average values are 43° for the long distance, 42° for the middle distance, and lower in sprint (37°). There are not significant differences in each phase, when the pace increases. For the three paces, the sweepback angle varies little during the ES and DC phases (Table 1b). It highly increases during the IN (from around 60° to around 180°) and is again stable during the UP and EX phases (close to 300°). At the three paces, the sweepback angle passed from 70° (ES) to 180° (IN) and then to 300° (EX): the leading edge changes from the fifth finger side to the thumb side (180°) halfway through IN, and then reverting back to an area between the fifth finger and the wrist at the end of UP. The flexion of the hand increases quite linearly in the cycle from 0° to 120° on average at the exit of the water (Table 1c and Figure 1a). During the most propulsive phases (IN and UP), the angle of flexion indicates that the hand is close to the perpendicular relative to the forward direction (between 82° and 86° for the insweep and between 112° and 117° for the upsweep). The angle of rotation indicates that the palm of the hand is most often oriented rearwardly relative to the axis of advancement (Table 1c and Figure 1b), with a beginning of orientation towards the inside during insweep (between 0° and 10°), then a higher increase during the upsweep to finish with an angle between 39° and 46°. The Table 1c and Figure 1c show that the angle of abduction is between 0° and 20° during the aquatic stroke.

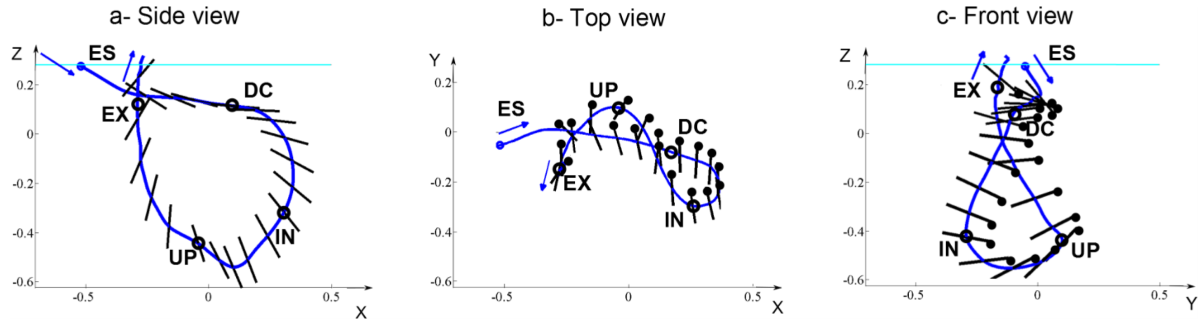

Figure 1: trajectory of the right hand (third finger) of one swimmer (S10) at the middle distance pace, and the hand orientation (black segment) relative to the trajectory. It represents the mean of all trajectories, in the three views: side (a), top (b) and front (c). Arrows indicate the entries and exits of the hand of the water. Circular markers represent the beginning of each phase: entry and stretch (ES), downsweep to catch (DC), insweep (IN), upsweep (UP), and exit (EX). Black point represents the thumb.

DISCUSSION: The results have shown that the increase of the pace essentially influences the velocity of the hand during the less propulsive phases. Orientation and hydrodynamic angles do not vary significantly, except the flexion during the entry and stretch phase. Thus it appears that during the most propulsive phases (upsweep and insweep), hydrodynamic parameters do not significantly evolve when the pace increases. As the water generated forces onto the hand are dependent on these parameters, we can conclude that the external forces applied during these phases will be close in the three paces. Thus, it appears that, to adapt their technique to increase swimming speed, swimmers favor the reduction of the duration of the propulsive phases, rather than by increasing the momentum in each underwater stroke.

CONCLUSION: It appears that these hydrodynamic parameters evolve little depending on the pace (except the velocity which evolves significantly during the less propulsive phases). This significant finding indicates that swimmers should adapt their technique by decreasing the duration of the less propulsive phases rather than increasing the propulsive peaks at each stroke of the arm.

REFERENCES:

Gourgoulis, V., Antoniou, P., Aggeloussis, N., Mavridis, G., Kasimatis, P., Vezos, N., Boli, A. & Mavromatis, G. (2010). Kinematic characteristics of the stroke and orientation of the hand during front crawl resisted swimming. *Journal of Sports Sciences*, 28, 1165-1173.

Maglischo, E.W., (2003). *Swimming Fastest*, Human Kinetics.

Monnet, T., Samson, M., Bernard, A., David, L. & Lacouture, P. (2014). Measurement of three dimensional hand kinematics during swimming with a motion capture system: a feasibility study. *Sports Engineering,* 17, 171-181.

Schleihauf, R., Gray, L. & DeRose, J., 1983. Three-dimensional analysis of hand propulsion in the sprint front crawl stroke. Biomechanics and medicine in swimming. In Hollander, P., Huijing, P. & de Groot, G. (Eds.), *Human Kinetics, Champaign* (pp 173-183).

Acknowledgement

The authors would like to thank the Stade Poitevin Swimming Club, and especially the coach Didier Stefanini and all swimmers who have participated in this study.