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Kinematic hand parameters in front crawl at different paces of swimming

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ABSTRACT

The aim of this study was to investigate the evolution of kinematic hand parameters (sweepback angle, angle of attack, velocity, acceleration and orientation of the hand relative to the absolute coordinate system) throughout an aquatic stroke and to study the possible modifications caused by a variation of the swimming pace. Seventeen competitive swimmers swam at 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 kinematic hand parameters evolve differently depending on the pace. Angle of attack, sweepback angle, acceleration and orientation of the hand do not vary significantly. The velocity of the hand increases when the pace increases, but only during the less propulsive phases (entry and stretch and downsweep to catch). The more the pace increases and the more the absolute durations of the entry and stretch and downsweep to catch phases decrease. Absolute durations of the insweep and upsweep phases remain constant. During these phases, the propulsive hand forces calculated do not vary significantly when the pace increases. The increase of swimming pace is then explained by the swimmer's capacity to maintain propulsive phases rather than increasing the force generation within each cycle.

1. Introduction

Propulsion in front crawl swimming is mainly provided by the upper limbs (Maglischo, 2003; Nakashima et al., 2012). Hands play an important role in this context. (Berger et al., 1995; Toussaint et al., 2000). In front crawl, the hand enters into the water in front of the swimmer and exits behind him. The aquatic strokes of the arms generate propulsive forces, which are defined as the component of resultant force in the swimming direction (Berger et al., 1999). Many authors have studied the links between these kinematic data (i.e., aquatic strokes) and the propulsive forces. According to Toussaint et al. (2000), the propulsive forces generated by the hand during a pull may be estimated given the lift and drag coefficients, velocity, and orientation of the hand during the stroke. Moreover, according to Schleihauf (1979), Berger et al. (1995) and Payton and Bartlett (1995) the drag and lift coefficients are dependent on the angle of attack and the sweepback angle. It was further shown that the acceleration of the hand played a significant role in propulsion, in particular through the added mass effect (Gardano and Dabnichki, 2006; Rouboa et al., 2006; Kudo et al., 2013; Sanders, 1999). Thus, knowledge of the angles of attack and sweepback angles, in addition to the velocity, acceleration, and orientation of the hand relative to the absolute coordinate system (these five parameters will be called "kinematic hand parameters"), will permit the analysis of both the technique of swimmers, and their effects on the resultant hand forces.

Indeed, kinematic hand parameters have been used in the calculation or measurements of forces, either experimentally, using numerical simulation, or theoretically. For example: Schleihauf et al. (1983), Berger et al. (1995) and Sanders (1999) have made dynamometric measurements in a towing tank from a modeled arm; Kudo and Lee (2010) have performed measurements from pressure sensors attached on a robotic arm; and, Bixler and Riewald (2002), Bilinauskaite et al. (2013), calculated lift and drag coefficients from a computational fluid dynamics (CFD) study. It appears that the data obtained in unsteady conditions yield results closer to reality than those in quasi-steady conditions (Gourgoulis et al., 2015). Sanders (1999) has proposed an analytical unsteady method that calculates the forces created by the hands from the angle of attack, sweepback angle, velocity and acceleration of the hand. We will use this method in the discussion to analyze the effect of measured kinematic parameters on the propulsive effort, and identify if there are differences between three swimming paces.

These kinematic hand parameters have been defined by different authors. The sweepback angle defines the leading edge of the hand relative to the water flow (Schleihauf et al., 1983). The angle of attack

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(preferred over pitch term) is the angle between the hand plane and the flow (Schleihauf et al., 1983; Lauder et al., 2001). The velocity of the hand is defined as the mean of the resultant velocities of the 2nd and the 5th metacarpophalangeal joints (Payton and Bartlett, 1995). Acceleration is thus the temporal derivative of this velocity. 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 coordinate system.

Despite the importance of these parameters in a coupled dynamic–kinematic study, there appear to be relatively few studies that have been conducted on a significant population. Previous studies have often investigated the kinematic data of only one or two swimmers (Schleihauf et al., 1983; Maglischo, 2003; Kudo and Lee, 2010), or a single pace (Gourgoulis et al., 2008; Gourgoulis et al., 2010; Gourgoulis et al., 2015), or on certain times of the path (Maglischo, 2003). There is not, to our knowledge, a study of a significant population (with sufficient swimmers) encompassing different paces that reports on the full range of kinematic hand parameters. Access to this type of data should allow a better understanding of how to organize competitive swimmers to perform and could serve coaches. In addition, they could also be used to calculate (or measure) and compare the forces generated by the hand at different swimming paces. Many studies have shown that the basic kinematic parameters evolve when the swimming pace increases (increasing of the stroke frequency and decreasing of the stroke length when the pace increases; Seifert and Chollet (2009)), but what about those kinematic hand parameters?

Thus, the purpose of the current research is to investigate the evolution of kinematic hand parameters over time, on a significant population of competitive swimmers. It was hypothesized that the modification of the pace implies a modification of these parameters.

2. Methods

2.1. Participants

Seventeen swimmers (nine men and eight women) participated in this study. Anthropometric details and experience level of each swimmer are given in the Table 1. All participants (or their parents) provided written consent prior to their participation. The test procedures were approved by the university ethics committee.

2.2. Test procedure

Experimentations were conducted in a specific pool of the Pprime Institute. Swimmers were asked to perform three trials at the three characteristic paces of swimming: sprint (corresponding to 50 m and 100 m distances), middle distance (200 m and 400 m) and long distance (800 m and 1500 m). Swimmers started from the edge of the pool and swam its full length. Halfway along the pool, the cameras recorded the trajectories of the markers as the swimmers swam past (Monnet et al., 2014). Velocity was measured to validate the requested swimming pace using a chronometer (IHM, C500 model). The stroke frequency was calculated based on external observation on three cycles of arm with a chrono-frequencymeter (IHM, C500 model). Each instant of the entry and the exit of the hand in water were carefully identified using a video system (Basler Cameras, 50 Hz of sampling frequency) coupled with the optoelectronic system. An aquatic stroke begins when the tip of the middle finger of the hand enters into the water and finishes when it exits.

2.3. Data processing

All the aquatic measurements were recorded from an optoelectronic system composed of eight Vicon T-40 cameras configured with 12.5 mm lenses. A CCD sensor with a resolution of 2352×1728 (4,064,256) pixels and a circular array of 320 red (623 nm) LEDs were mounted around each camera. The sampling frequency was 200 Hz, and the dimension of the calibrated volume was about 1.1 m long, 1 m wide and 1 m high. 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 (Fig. 1).

2.4. Data analysis

Several methods have been proposed to calculate the sweepback and attack angles (Lauder et al., 2001). In our study, the method described in Schleihauf (1979) and used in Gourgoulis et al. (2008) has been selected. According to this approach, four anatomical landmarks

Table 1
Anthropometric characteristics and level of the swimmers. SD = standard deviation.

	Height (m)	Mass (kg)	Age (years)	Gender	Arm length (mm)			Level	% World record
					Forearm	Upper-arm	Hand		
S1	1.78	75	22	M	250	300	205	Regional	78.2
S2	1.85	76	23	M	275	340	205	Regional	78.8
S3	1.77	78	22	M	240	330	210	Regional	82.4
S4	1.8	76	22	M	250	325	195	National	90.2
S5	1.77	81	18	M	255	320	205	National	86.2
S6	1.72	70	17	M	250	315	185	National	85.1
S7	1.84	82	21	M	260	345	195	National	85.4
S8	1.7	55	18	F	240	315	185	National	85.2
S9	1.67	54	17	F	225	300	180	National	87.8
S10	1.87	84	20	M	280	360	195	National	86.8
S11	1.62	50	19	F	225	300	165	Regional	78.8
S12	1.65	55	19	F	220	300	185	Regional	81.9
S13	1.83	80	22	M	260	340	195	Regional	82.3
S14	1.78	70	21	F	235	320	195	Regional	80.2
S15	1.8	72	25	F	245	320	200	National	86.7
S16	1.74	66	20	F	250	320	180	Regional	82.5
S17	1.68	60	20	F	240	310	175	National	86.1
Mean	1.76	69.6	20.4		247.1	321.2	191.5		83.8
SD	0.07	10.7	2.1		15.9	16.9	11.9		3.4

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