KINEMATIC AND DYNAMIC COUPLED MEASUREMENTS IN TETHERED FRONT CRAWL SWIMMING

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KEY WORDS: piezoelectric balance, optoelectronic system, mean force, stroke frequency.

INTRODUCTION: Force measurements of athletes in aquatic environments are difficult to perform. Competitive swimming has been confronted with this problem for many years. Tethered swimming is a means used to measure propulsive forces (Martin, Yeater & White, 1981). According to Filho and Denadai (2008), this method is often used to measure the performance level of swimmers and also as a training resource. Its validity has been shown on numerous occasions, notably in its good correlation between swimming velocity, stroke frequency and the measured forces (Yeater, Martin, White & Gilson, 1981; Morouço, Keskinen, Vilas-Boas & Fernandes, 2011). This method has good test–retest reliability (Kjendlie & Thorsvald, 2006), and it provides muscle activity patterns very similar to those displayed in free swimming (Bollens, Annemans, Vaes, & Clarys, 1988). Even if there are questions about the swimming technique used in the tethered swimming compared to the free swimming, this method is important to know the forces created by the stroke technique, especially by the arms. It seems also interesting to measure the forces in the three characteristic paces (long distance, middle distance and sprint). This kinematic and dynamic coupled method is transferable in training pool, and then it could be an everyday tool for swimmers and coaches to measure and to improve the technical swimmers.

METHOD: Experiments were conducted in a 1.5 m wide, 1.5 m deep, 25 m long channel at the Pprime Institute, Poitiers. The propulsive forces were measured from a completely tethered swimmer, acquired at 1000 Hz by a mass balance (ref. Kistler Four-Component Force Measurement, Type 5070A.). The participants were connected to the balance by an undeformable rope (stainless steel thickness 2 mm), connected to a rigid and dimensionally stable belt. The kinematic measurements were made from an opto-electronic system (cameras and post-processing) that tracks reflective markers positioned on the joints of the swimmer's arm. The swimmer swam (with both arms and legs) at an announced pace (long distance, middle distance and sprint) for 14 arm strokes without breathing (to eliminate the possible effects of breathing on the measurements). Acquisition commences after 4 strokes to reach equilibrium of the swimming, resulting in 10 strokes per acquisition.

Data processing

The kinematic measurements were recorded from an optoelectronic system composed of four cameras that tracked seven reflective markers of 14 mm diameter. Three markers were fixed on the right hand (the tip of the third finger, and the second and fifth metacarpophalangeal joints), two on the wrist (radial styloid and ulnar styloid), and one on the elbow and shoulder. The cameras acquired images at 200 Hz. The force data was synchronized with the kinematic data using an automatic trigger.

Data analysis

Six kinematic and four dynamic parameters were calculated. To simultaneously analyse the trajectory of the arm with the measured forces, the whole underwater arm stroke was divided into distinct phases, following the model of Maglischo (2003). The aquatic stroke was decomposed in five phases with respect to the right hand: entry and stretch (ES, from entry of the tip of the middle finger 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). The objective is to measure the forces generated within each phase.

Kinematic parameters:
- Stroke frequency of the arms.
- Velocity and acceleration of the hand, forearm and arm.
- Sweepback and angle of attack of the flow relative to the hand.
- Orientation of the arm segments relative to the global reference system.

Dynamic parameters :
- Tether forces during 10 arm strokes.
- Mean tether force during 10 arm strokes.
- Peak tether force during 10 arm strokes.
- Mean of peak tether force during 10 arm strokes.

TABLE AND FIGURE: Values of forces (peak, maximum and mean) are shown for one swimmer at three characteristics paces in Figure 1. Table 1 allows to compare the data forces at the three paces.

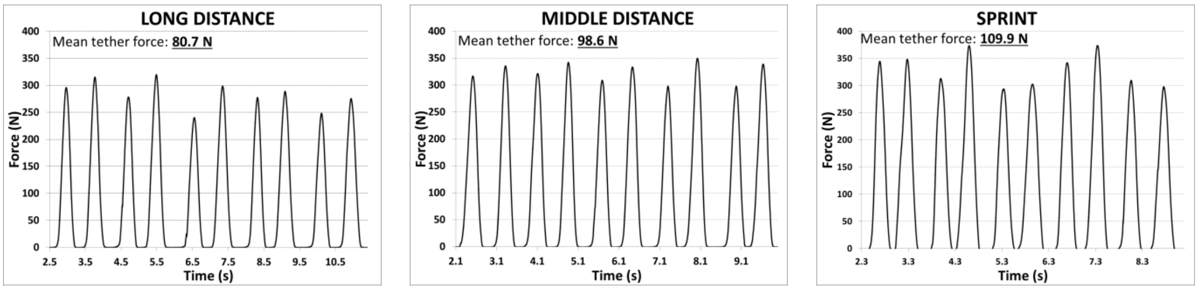

Figure 1: A measured force–time curve for one swimmer (and mean tether force) during 10 arm strokes, at the three paces of swimming.

Table 1
Peak tether force, maximum tether force and mean tether force, and stroke frequency for one swimmer at the three paces of swimming.

	Maximum force (N)		
	Long distance	Middle distance	Sprint
Peak 1	289	311	344
Peak 2	308	330	346
Peak 3	269	315	311
Peak 4	314	338	373
Peak 5	234	301	292
Peak 6	292	327	301
Peak 7	264	298	341
Peak 8	280	343	373
Peak 9	237	290	309
Peak 10	269	331	297
Mean	**275.6**	**318.4**	**328.7**
Max	**314**	**343**	**373**
Stroke frequency (cycles/min)	*33.7*	*37.8*	*43.5*

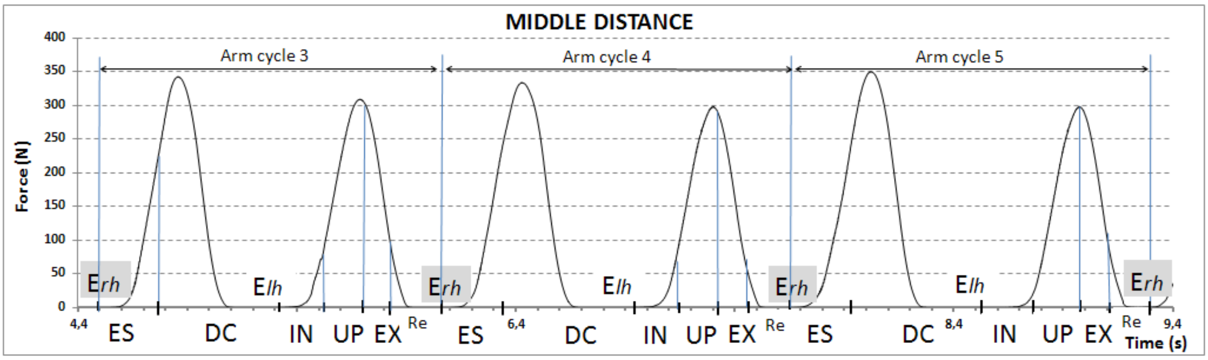

Figure 2: example of kinematic-dynamic coupled measurements. The curve represents a force signal measured for a swimmer during 3 right arms cycles (3rd, 4th and 5th). E*rh* defines the entry of the right hand in the water; E*lh*: the entry of the left hand. ES: entry and stretch phase; DC: downsweep to catch; IN: insweep; UP: upsweep; EX: exit; Re: recovery of the arm.

During the ES and DC phases of the right arm, there is a peak of force mainly from the action of the left arm. During the IN of the right arm, the measured forces begin to increase. Force peaks are obtained during the UP phase. However it is found that during the EX phase, which is non-propulsive because the hand comes back forward, the measured forces are important. It seems therefore be a time lag between the arm action and the measured forces. This phase shift is probably due to the deformation of the fixing system and in particular the elongation of the cable and the deformation of the belt.

DISCUSSION: It appears that the more the pace increases, the more the peaks of force, the average, and the mean of the peaks increase. The simultaneously dynamic-kinematic measurement is difficult because there is a deformation of the measurement system. Indeed, when the force goes to zero, the cable becomes slack, and the retensioning of the cable could result in a stress wave that will cause a spike in the force measurement. Moreover, the deformation of the belt-swimmer system amplifies the retensioning of the rope, creating perhaps a temporal phase shift between the dynamic measurements and the of the arms actions on the water. It will be interesting to discuss, during this session, about the implementation of this device, which provides important dynamic data for the coaches and swimmers. Indeed, this experimental device has the advantage to be transposed to a training pool without much technological difficulties. It therefore deserves to be improved to measure the most simultaneously possible, the forces produced with the stroke arms, especially during acceleration phases of the segments.

Acknowledgements: This applied session is kindly supported by Qualisys and Trinoma

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Acknowledgement

The authors would like to thank the Stade Poitevin Swimming Club and the swimmers of the Faculty of Sport Sciences of Poitiers, who have participated in this applied session.