Portuguese Journal of Sport Sciences
11 (Suppl. 2), 2011

THE EFFECT OF FATIGUE ON THE 200 M FRONT CRAWL UNDERWATER STROKE PATTERN

Pedro Figueiredo[1,2], Rafael Nazário[1], André Cereja[1], João Paulo Vilas-Boas[1,2] and Ricardo J Fernandes[1,2]

CIFI²D, Faculty of Sport, University of Porto, Porto, Portugal[1]
Porto Biomechanics Laboratory (LABIOMEP), University of Porto, Porto, Portugal[2]

The present study aimed to investigate the effect of fatigue on the spatial underwater swimming arm-stroke pattern. Ten male swimmers performed a 200 m front crawl at maximal intensity. The kinematic stroke parameters recorded by six cameras were: mean swim velocity, stroke length, stroke frequency, and a number of upper limb linear and angular displacements and velocities. Differences between the four laps were assessed with a repeated measure ANOVA and effect sizes. Fatigue effect was shown in the significant decrease of the velocity (swimming and arm), depths and elbow angle at the end of backward movement. The present findings could be useful for coaches in evaluating fatigue effects on the swimming technique.

KEY WORDS: swimming technique, kinematics, fatigue, front crawl

INTRODUCTION: In swimming, propulsive force is induced by arms and legs motion. During the front crawl, the propulsive force is known to be mainly generated by the arm-stroke motion (Deschodt et al., 1999). Propulsive forces were strongly linked to kinematic hand parameters as observed in the different models of hand force calculations (e.g. Schleihauf 1979; Berger et al., 1995). Also it is suggested that swimming velocity (v) could partly be explained by horizontal or vertical hand displacements during the arm stroke (Deschodt et al., 1996). However, studies on the effect of fatigue in the kinematics of arm stroke motion during high intensity swim are limited. Deschodt (1999) reported a significant decrease in the displacement of the wrist in the horizontal axis following a 6 × 50 m front crawl swim at maximal velocity. However, Aujouannet et al. (2006) found, for a protocol of 4 x 50 m front crawl at maximal intensity, that fatigue was characterized by spatial stability of fingertip's trajectory. Additionally, Suito et al. (2008) showed that hand velocity, and peak angular velocity of shoulder adduction were reduced significantly from the first half to the second half of an all-out 100 m front crawl, in agreement with the reports of Toussaint et al. (2006). The present study aimed to investigate the effects of fatigue on underwater arm-stroke motion during 200 m front crawl performed at maximal intensity.

METHODS: Ten high performance level male swimmers participated in this study (average ± SD: aged 21.6 ± 2.4 yrs; height 185.2 ± 6.8 cm; arm span 188.7 ± 8.4 cm; body mass 76.4 ± 6.1 kg). All swimmers (mean performance in a 200 m race = 91.6 ± 2.1% of the 25 m pool world record) had 11.9 ± 3.5 yrs experience as competitive swimmers. After a moderate intensity individual warm-up, totalling 1000 m, swimmers performed a 200 m front crawl race at maximal intensity, from a push off start, to eliminate the influence of the dive in the analysis of the first stroke cycle. Six synchronised video cameras (Sony® DCR-HC42E) were used to record the event (four under and two above water; the above water angle between cameras was ≈100º, while the angles between adjacent underwater cameras varied from 75º to 110º). Three-dimensional reconstruction of 21 body landmarks (with DLT; Abdel-Aziz & Karara, 1971) using Zatsiorsky anatomical model adapted by de Leva (1996) was digitised at 50 Hz. A calibration frame (3 x 2 x 3 m for the horizontal, vertical and lateral directions; 30 calibration points) and a 6 Hz low pass digital filter were used. The accuracy was calculated through RMS reconstruction errors of the calibration frame, which for x, y and z axes were: (i) 3.9, 3.7 and 3.3 mm respectively for the above water view and (ii) 3.4, 2.5 and 3.2 mm respectively for the underwater view. The reliability was determined digitizing ten times the same stroke cycle. Small standard deviation (s) and CV for the repeated digitisations indicated acceptable reliability for velocity (s: 0.03 $m.s^{-1}$, CV: 2.05%) and displacement (s: 0.004 m, CV: 1.72%). One complete arm stroke cycle, without breathing, was recorded for each 50 m of the 200 m front crawl. Test sessions took place in a 25 m indoor pool.

The mean horizontal velocity was calculated by dividing the swimmer's mean centre of mass horizontal displacement by the time spent to complete one stroke cycle. Stroke frequency was the inverse of the time to complete one stroke cycle. Stroke length was the horizontal displacement of the centre of mass during one stroke cycle. Angular velocity of the arm was calculated based on the representation of the arm by a stick connecting the shoulder joint centre and the centre of mass of the segment. The backward displacement amplitude and slip amplitude were calculated through the difference between the most forward point and the most backward position of fingertip's (third distal phalanx of the finger) and between entry and exit fingertip's coordinates, respectively. The vertical motion of the upper limb was represented by the fingertip, wrist, and elbow in y direction of displacement and referenced to an external point. The lateral motion of the upper limb was calculated as the absolute z displacement, referenced to the swimmer's centre of mass. The three-dimensional elbow angle was calculated in four time moments within the underwater stroke cycle: (i) entry of the hand in the water (A - entry); (ii) beginning of finger backward movement (B – first back); (iii) finger vertically aligned with the shoulder (C – shoulder x); (iv) end of backward movement (D – end back). These time moments were calculated based on the horizontal displacement of the finger and shoulder during the stroke cycle. The elbow angle range during the pull and push phases was calculated as: C-B and D-C, respectively.

Mean (SD) computations for descriptive analysis were obtained for all variables (normal Gaussian distribution of the data was verified by the Shapiro–Wilk's test). A one-way repeated measure ANOVA with Bonferroni post hoc was used to compare the variables across the 200 m. Statistical analysis was performed using STATA 10.1 (StataCorp, USA) and $p<0.05$ accepted as significant.

RESULTS: Mean (SD), p- and F-values of the repeated measures ANOVA, and effects sizes are displayed in Table 1 for the variables tested. Changes in race parameters were observed as denoted by the significance level and large effect sizes. Differences for the underwater arm-stroke, depths, maximal elbow width and the magnitude of the elbow angle at the end back point were significant across the 200 m front crawl.

Table 1
Mean data (SD) and statistical comparisons between the laps across the 200 m front crawl for the following variables: race parameters, arm, elbow angle.

Parameters	Lap 1	Lap 2	Lap 3	Lap 4	$F_{(3,27)}$	p	*f*
Velocity ($m.s^{-1}$)	1.57 (0.08)	1.39[a] (0.06)	1.34[a] (0.07)	1.35[a] (0.06)	24.58	<0.001	1.26
Stroke length (m)	2.29 (0.23)	2.21 (0.17)	2.19 (0.13)	2.12[a,b,c] (0.13)	4.55	0.01	0.32
Stroke frequency (Hz)	0.68 (0.09)	0.63 (0.06)	0.61[a] (0.05)	0.64 (0.05)	5.08	0.006	0.39
Arm angular v ($degree.s^{-1}$)	2.73 (0.42)	2.50 (0.26)	2.43[a] (0.26)	2.38[a] (0.25)	5.18	0.006	0.40
Backward amplitude (m)	0.68 (0.06)	0.68 (0.07)	0.71 (0.09)	0.69 (0.10)	0.45	0.72	0.00
Amplitude slip (m)	0.56 (0.27)	0.57 (0.32)	0.56 (0.33)	0.58 (0.31)	0.06	0.98	0.00

(continued on next page)

Table 1. (continued)

Parameters	Lap 1	Lap 2	Lap 3	Lap 4	F(3,27)	p	f
Max. finger depth (m)	0.72 (0.06)	0.71 (0.06)	0.70 (0.05)	0.69[a] (0.06)	4.90	0.008	0.17
Max. wrist depth (m)	0.57 (0.06)	0.56 (0.06)	0.55 (0.05)	0.54[a] (0.06)	4.50	0.001	0.18
Max. elbow depth (m)	0.36 (0.04)	0.35 (0.04)	0.34 (0.04)	0.33[a,b] (0.06)	6.98	0.001	0.21
Max. elbow width (m)	0.31 (0.05)	0.33 (0.06)	0.34 (0.05)	0.35[a] (0.05)	4.79	0.008	0.23
Finger width range (m)	0.35 (0.08)	0.35 (0.10)	0.33 (0.10)	0.35 (0.05)	0.75	0.53	0.00
Wrist width range (m)	0.29 (0.05)	0.30 (0.08)	0.27 (0.08)	0.27 (0.06)	1.30	0.29	0.09
Elbow width range (m)	0.22 (0.05)	0.23 (0.05)	0.23 (0.05)	0.23 (0.05)	1.03	0.39	0.03
Elbow angle: entry (º)	149.4 (12.1)	145.1 (14.0)	149.1 (11.4)	146.0 (12.8)	1.61	0.21	0.10
Elbow angle: first back (º)	149.7 (11.2)	152.9 (6.8)	148.4 (10.6)	149.0 (8.1)	1.85	0.16	0.13
Elbow angle: shoulder x (º)	102.2 (13.4)	101.2 (15.5)	96.8 (12.5)	95.9 (10.7)	2.24	0.11	0.16
Elbow angle: end back (º)	143.0 (3.3)	142.6 (7.6)	141.3 (6.6)	136.3[a,b] (4.8)	5.57	0.004	0.43
Elbow angle: range of pull (º)	47.6 (14.7)	51.7 (14.9)	51.6 (17.5)	53.0 (14.4)	1.06	0.38	0.03
Elbow angle: range of push (º)	40.8 (14.9)	41.4 (19.1)	44.4 (14.8)	40.3 (12.6)	0.56	0.64	0.00

[a,b,c] Significantly different from the first, second and third lap, respectively. p<0.05.

DISCUSSION: Race parameters changed as expected and in accordance with the literature regarding the stroke parameters management (Craig et al., 1985; Alberty et al., 2005). The decrease across the 200 m in the angular velocity of the arm was expected as swimming v decreased as well, since the upper limb is assumed to be the main generator of the propulsive force, it is quite likely that the decreased swimming v was caused by the reduced hand velocity. These findings were in accordance with the reports for the 100 m front crawl (Toussaint et al., 2006; Suito et al., 2008). Backward amplitude was lower than the value reported by Deschodt et al. (1999; 0.81 m). Nevertheless, depths were similar to the values described previously (Deschodt et al., 1999; McCabe et al., 2011), however both of these studies a 25 m maximum protocol was performed. A decrease of all the measured depths was observed from the first to the last lap. Such results could reflect the absolute decrease in elbow angle: shoulder x, which was not found to be statistically different, but presented a medium size effect. It should be also affected by the increase of stroke frequency and their influence in the body role, as reported by Psycharakis & Sanders (2008) in the final 50 m lap of the 200 m front crawl. The elbow angle end back values were slightly lower than the ones presented by McCabe et al. (2011), probably because of the different velocities and protocol used. The decreased in this angle across the race suggests a reduction of the power output (Toussaint et al., 2006) and also a decrease in the propulsive forces produced in the push phase, since triceps brachii fatigues (Aujouannet et al., 2006). However, backward amplitude remained statistically stable, which suggests that the most forward point is increased, possibly due to an augmented glide and of the non-propulsive phases, consequently the decrease in the swimming v. The elbow angle: shoulder x values presented in the first lap were similar or lower than the values in the literature (Cappaert, 1999; McCabe et al., 2011). The decrease that occurs along the effort tending to the 90º, that some authors claim to be the recommended angle (e.g. Costill et al., 1992), could be to compensate the increased width of the elbow. The range of the angles were maintained throughout the effort and were similar to the ones presented previously (Payton et al., 1999; McCabe et al., 2011).

CONCLUSION: The fatigue induced by a maximal 200 m front crawl effort provoked changes in spatial underwater upper limb kinematical parameters. These results could be useful for coaches to evaluate the general and individual effects of fatigue on technical parameters of front crawl.

REFERENCES:

Abdel-Aziz, Y., & Karara, H. (1971). Direct linear transformation: from comparator coordinates into object coordinates in close range photogrammetry. In *Proceedings of the symposium on close- range photogrammetry* (pp. 1–18). Illinois: Church Falls.

Alberty, M., Sidney, M., Huot-Marchand, F., Hespel, J. M., & Pelayo, P. (2005). Intracyclic velocity variations and arm coordination during exhaustive exercise in front crawl stroke. *International Journal of Sports Medicine, 26*(6), 471-475.

Aujouannet, Y. A., Bonifazi, M., Hintzy, F., Vuillerme, N., & Rouard, A. H. (2006). Effects of a high-intensity swim test on kinematic parameters in high-level athletes. *Applied Physiology, Nutrition and Metabolism, 31*(2), 150-158.

Berger, M. A., de Groot, G., & Hollander, A. P. (1995). Hydrodynamic drag and lift forces on human hand/arm models. *Journal of Biomechanics, 28*(2), 125-133.

Cappaert, J. M. (1999). *Biomechanics of swimming analysed by three-dimensional techniques*. Jyvaskyla, Finland: University of Jyvaskyla.

Costill, D. L., Maglischo, E. W., & Richardson, A. B. (1992). *Swimming*. London: Blackwell Scientific.

Craig, A. B., Jr., Skehan, P. L., Pawelczyk, J. A., & Boomer, W. L. (1985). Velocity, stroke rate, and distance per stroke during elite swimming competition. *Med Sci Sports Exerc, 17*(6), 625-634.

de Leva, P. (1996). Adjustments to Zatsiorsky-Seluyanov's segment inertia parameters. *Journal of Biomechanics, 29*(9), 1223-1230.

Deschodt, V. (1999). Modifications de la trajectoire aquatique du poignet liées à l'apparition de la fatigue lors d'exercices intermittents en natation. *Science et Motricité,* (37), 19–25.

Deschodt, V., Rouard, A. H., & Monteil, K. M. (1996). Relationships between the three coordinates of the upper limb joints with swimming velocity. In J. P. Troup, A. P. Hollander, D. Strasse, S. W. Trappe, J. M. Cappaert & T. A. Trappe (Eds.), *Biomechanics and medicine in swimming VII* (pp. 52–58). London: E & FN Spon.

Deschodt, V. J., Arsac, L. M., & Rouard, A. H. (1999). Relative contribution of arms and legs in humans to propulsion in 25-m sprint front-crawl swimming. *European Journal of Applied Physiolology and Occupational Physiology, 80*(3), 192-199.

McCabe, C. B., Psycharakis, S., & Sanders, R. (2011). Kinematic differences between front crawl sprint and distance swimmers at sprint pace. *Journal of Sports Science, 29*(2), 115-123.

Payton, C. J., Bartlett, R. M., Baltzopoulos, V., & Coombs, R. (1999). Upper extremity kinematics and body roll during preferred-side breathing and breath-holding front crawl swimming. *Journal of Sports Science, 17*(9), 689-696.

Psycharakis, S. G., & Sanders, R. H. (2008). Shoulder and hip roll changes during 200-m front crawl swimming. *Medicine and Science in Sports and Exercise, 40*(12), 2129-2136.

Schleihauf, R. (1979). A hydrodynamic analysis of swimming propulsion. In J. Terauds & W. Bendingfied (Eds.), *Swimming III* (pp. 70-117). Baltimore: University Park Press.

Suito, H., Ikegami, Y., Nunome, H., Sano, S., Shinkai, H., & Tsujimoto, N. (2008). The effect of fatigue on the underwater arm stroke motion in the 100-m front crawl. *Journal of Applied Biomechanics, 24*(4), 316-324.

Toussaint, H. M., Carol, A., Kranenborg, H., & Truijens, M. J. (2006). Effect of fatigue on stroking characteristics in an arms-only 100-m front-crawl race. *Medicine and Science in Sports and Exercise, 38*(9), 1635-1642.

Acknowledgment

This investigation was supported by grants of Portuguese Science and Technology Foundation (SFRH/BD/38462/2007) (PTDC/DES/101224/2008).