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LOWER LIMBS JOINTS MOTION DURING SUBMAXIMAL 100-M BUTTERFLY

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The aim of this study was to analyze the differences in the angular kinematics of the downbeat actions among four laps of a submaximal 100-m butterfly swim. Four female trained swimmers performed a 100-m butterfly at submaximal intensity (80% of individual's best performance). One above and one underwater camera, positioned to capture motion in the swimmer's sagittal plane, were used for movement analysis. Findings revealed that fatigue seems to affect the segmental co-ordination during downbeat actions at third and fourth laps. During the last laps swimmers registered a shorter time to extension of the knee joint in the second downbeat. It was also observed at third and fourth laps a decrease in knee and ankle angular displacement and velocity in both downbeats.

KEYWORDS: angular kinematics, segmental co-ordination, swimming, downbeats.

INTRODUCTION: In the butterfly swimming technique, the lower limb cycle consists of one upbeat and one downbeat, normally existing two leg kicks cycles during each stroke (Maglischo, 2003). The downbeat actions are connected to the propulsion through lower limb motion, and have an important contribution to reduce the swimmer's deceleration that occurs particularly during the arm´s recovery and entry (Barbosa et al., 2008). Some kinematic studies of the lower limbs motion in butterfly technique (e.g. Barthels & Adrian, 1971; Sanders et al., 1995; Arellano et al., 2003) provided relevant information for training and performance diagnosis. Nevertheless, none of them analyzed how downbeats actions should be performed to obtain the optimal mechanical output during a submaximal 100-m effort.
The biomechanical factors that specified the sequence of movements or parts of movements (e.g. joint angular kinematics) are potentially fundamental for the technique developments required to enhance the performance, mainly in throwing, kicking and jumping movements (Gittões & Wilson, 2010). Although the lower limbs motion of the butterfly technique is not only comprised by the downbeats, these actions represent one of the determinant factors to maintain a specific swimming velocity, particularly at submaximal events (Barbosa et al., 2008). Moreover, according to Osborough & Peyrebrune (2009), it seems relevant to understand the possible fatigue effects on lower limb co-ordination. The aim of the present study was to analyze the differences in lower limbs angular kinematics (hip, knee and ankle joints) used during butterfly leg downbeats among four laps of a submaximal 100-m butterfly effort.

METHODS: Four female trained swimmers (mean ± SD: 16.25 ± 1.25 years old, 1.65 ± 0.08 m, 56.97 ± 3.53 kg, 10.3 ± 2.6 years of training background and 62.91 ± 1.01 s at the long course 100-m butterfly), participated in the study. The test session took place in a 25 m indoor swimming pool. Briefly, each participant, after a moderate intensity individual warm-up, performed a 100-m butterfly test at submaximal intensity (approximately 80% of their best performance in 100-m butterfly), with a start in water. The swimmers were monitored when passing through a specific vertically and horizontally pre-calibrated plane with 6.3 m² of dimension. Six calibration points were used, and synchronization of images was obtained using a pair of lights, observable in the field of view of each one of the two video cameras (Sony®, DCR-HC42E, Japan). One camera was placed 0.9 m above the water surface and the other was kept underwater (Sony®, SPK-HCB box) at a depth of 1.60 m. Both were located at a distance of 11.5 m from the starting wall of the pool. Cameras were placed at about 9 m from the plane of movement. One complete non breathing arm stroke cycle, of each 25 m lap of the 100-m butterfly was manually digitized using APASystem (Ariel Dynamics, USA) at a frequency of 50 Hz, manually and frame by frame. Zatsiorsky & Seluyanov's model, adapted by de Leva (1996), was used to analyze kinematic data. Thirteen anatomical landmarks were digitized in each frame to represent the segments of the head, trunk (divided into three articulated parts), upper arm, forearm, hand, thigh, shank and feet. 2D reconstruction was accomplished using Direct Linear Transformation algorithm (Abdel-Aziz & Karara, 1971), and a low pass digital filter of 5 Hz. The video images were digitized in order to assess the angular displacement and their first derivative (peak of angular velocity and correspondent time) of the hip, knee and ankle joints (Figure 1).

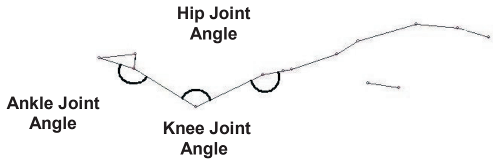

Figure 1: The definition of the joint angles of the swimmer performing butterfly technique.

Root Mean Square (RMS) reconstruction errors of four validations points on the calibration frame, which did not serve as control points, were respectively for *x* and *y* axes: (i) 0.257 and 0.075 mm, representing 0.12 and 0.18 % of the calibrated space for above the water and (ii) 0.013 and 0.016 mm, representing 0.16 and 0.41% of the calibrated space for underwater views. The butterfly kick was divided into four phases: (i) *First Downbeat*, corresponding to the time between the high and low break-even points of the feet during the first kick; (ii) *First Upbeat*, corresponding to the time between the low and high break-even points of the feet during the first kick; (iii) *Second Downbeat*, corresponding to the time between the high and low break-even points of the feet during the second kick; (iv) *Second Upbeat,* corresponding to the time between the low and high break-even points of the feet during second kick. The phase's duration were normalized for the time duration of the one kick stroke cycle. Repeatability and limits of agreement of the digitizing procedure was assessed by two calculated consecutive digitization of a randomly selected trial using the Bland & Altman method (1986), being: (i) 5.93˚ [- 6.056 to 7.085] for joint hip angle; (ii) 2.75˚ [- 23.822 to 25.314] for joint knee angle; (iii) 8.32˚ [- 27.296 to 29.871] for joint ankle angle; (iv) 4.17˚ [-15.356 to 19.689] for hip angular velocity; (v) 8.22 rad.s^{-1} [-6.996 to 8.784] for knee angular velocity; and (vi) 7.52 rad.s^{-1} [-64.905 to 66.171] for ankle angular velocity. A non parametric test (Friedman's) was used to compare first, second, third and fourth stroke cycle correspondent to each lap due to the small sample size. The level of significance was set as $\alpha = 0.05$.

RESULTS: Data concerning joint angular displacement, peak of angular velocity and respective time of hip, knee and ankle joint extension for all laps are presented in Table 1.
First and second laps registered a greater knee and ankle angular displacement at first and second downbeats in comparison to the remaining laps. Considering the peak of angular velocity for knee and ankle extension, first and second laps reported greater value at both downbeats than third and fourth laps. Regarding the temporal analysis at first lap, it was observed that knee registered a delayed peak of angular velocity than third and fourth laps for the second downbeat.

DISCUSSION: The present study investigated the angular kinematics of the lower limbs joints motion used in downbeats of the butterfly technique during a submaximal 100-m butterfly event. In comparison to the third and fourth, the first and second laps registered a greater knee joint angular displacement at both downbeats. In fact, this is probably explained by the reduced lower limbs amplitude during the third and fourth laps, attributable to local

Table 1
Mean ± SD values for all subjects for angular displacement, peak of angular velocity, and respective time for the hip, knee and ankle joints, respectively, for the first, second, third and fourth laps, at first and second downbeats of butterfly kick.

Variables	Downbeats	First lap	Second lap	Third lap	Fourth lap
Hip (°)	First	13.9 ± 6.7	24.3 ± 7.1	17.9 ± 8.8	17.9 ± 7.3
	Second	38.8 ± 12.7	32.1 ± 16.1	38.4 ± 13.2	33.2 ± 14.1
Hip ($rad.s^{-1}$)	First	258.2 ± 22.3	250.5 ± 26.8	256.1 ± 22.1	251.6 ± 20.5
	Second	253.3 ± 28.2	256.1 ± 13.2	273.1 ± 19.3	242.6 ± 19.9
Hip (T%)	First	20.2 ± 6.6	18.7 ± 6.2	22.7 ± 3.9	21.5 ± 3.2
	Second	62.5 ± 8.0	67.5 ± 6.6	67.2 ± 9.6	74.5 ± 12.6
Knee (º)	First	63.1 ± 15.3	61.6 ± 10.7	26.3 ± 13.7◊●	27.3 ± 14.3◊●
	Second	61.5 ± 7.4	58.3 ± 9.9	21.8 ± 12.2◊●	14.5 ± 17.1◊●
Knee ($rad.s^{-1}$)	First	384.2 ± 15.4	382.1 ± 17.7	196.5 ± 26.9◊●	185.7 ± 23.7◊●
	Second	398 ± 36.7	386.4 ± 34.1	206.8 ± 12.9◊●	203.5 ± 10.5◊●
Knee (T%)	First	19.2 ± 8.9	22.2 ± 8.2	26.2 ± 2.2	26.2 ± 1.8
	Second	83.7 ± 7.9	75.5 ± 6.6	65.7 ± 2.3◊	65.2 ± 8.1◊
Ankle (º)	First	91.1 ± 16.1	81.1 ± 12.5	34.3 ± 15.1◊●	27.3 ± 10.8◊●
	Second	72.9 ± 15.9	70.9 ± 12.2	28.8 ± 10.7◊●	26.3 ± 5.9◊●
Ankle ($rad.s^{-1}$)	First	346.5 ± 48.7	313.7 ± 56.4	214.6 ± 57.6◊●	212.2 ± 46.6◊●
	Second	305.8 ± 45.8	300.1 ± 46.6	215.2 ± 59.8◊●	205.1 ± 56.1◊●
Ankle (T%)	First	26.2 ± 2.4	27.7 ± 4.6	29.2 ± 2.6	30.7 ± 7.8
	Second	89.7 ± 5.7	85.3 ± 3.8	82.7 ± 3.40	83.7 ± 6.3

Note: ◊, ● Significant differences in comparison with first and second laps, respectively; $p < 0.05$.

fatigue. According to Rejman & Ochmann (2005), with the increasing of the lower limbs amplitude, swimmers create a bigger wake of counter-rotation vortices and maximise the leg propulsion, but, when the leg amplitude increase, the swimmer's form drag will also increase. Moreover, it has been suggested that the reduction of the kick amplitude (Sanders et al., 1995; Arellano et al., 2003), the increase of kick frequency, and the increase of the knee's angle during the downbeat (Arellano et al. 2003) are linked to the lower negative acceleration during arm's recovery and entry (Barthels & Adrian, 1971; Barbosa et al., 2008).

In addition, when comparing the four laps for the peak of joint angular velocity of knee and ankle extension, the first and second laps registered a greater value than third and fourth. At correspondent time for the peak of joint angular velocity of knee extension, swimmers probably more fatigued, registered a new inter-segmental organization, which was observed by the lower values at second downbeat for third and fourth laps than the obtained for the first one. Rodacki et al. 2001 have demonstrated an earlier achievement of peak of knee angular velocity performed under fatigue, meaning the reorganization of the movement coordination. The importance of knee and ankle (flexion and extension) angular velocity have been considered to be particularly influential in generating the acceleration during downbeats of the butterfly technique (Sanders et al., 1995).

CONCLUSION: The findings of the present study revealed that fatigue seems to affect the segmental co-ordination during downbeats actions at last event's laps. Swimmers registered an earlier time at third and fourth laps to perform the maximal knee joint angular velocity during the second downbeat. Moreover, in both downbeats, swimmers presented an evident decrease in knee and ankle extension for last laps than for the first and second laps. It is recommended that coaches begin monitoring the leg kicks variation under condition of fatigue to improve inter-segmental co-ordination, which can be the determining factor of success of the butterfly technique.

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