

# Inter-Limb Coordinative Structure in a 200 m Front Crawl Event

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**Abstract:** The Index of Coordination has been currently used as a tool that measures the inter-arm lag time between propulsive phases in front crawl swimming. The aim of the present study was to assess the inter-arm coordinative structure during a 200m front crawl maximal effort, as well as to understand its interplay with the stroking parameters. One complete arm stroke cycle, without breathing, was digitized and analysed the relative duration of the different phases and identified the model of arm coordination by using the Index of Coordination in each length of 50m of the 200m front crawl. A one way repeated measures ANOVA, with Tukey post-hoc test was used to compare all the variables, and Pearson correlation coefficients were computed between Index of Coordination and the biomechanical (velocity, stroke rate, stroke length) and coordinative parameters ( $p < 0.05$ ). Results showed an increase in the relative duration of the propulsive phases, which induced an increase in the Index of Coordination as fatigue developed in relation to a decrease in velocity, stroke rate and stroke length. Additionally, Index of Coordination was inversely related with entry/catch ( $r = -0.78$ ) and the non-propulsive phases ( $r = -0.97$ ), and positive related with the pull ( $r = 0.54$ ), push ( $r = 0.78$ ) and propulsive phases ( $r = 0.97$ ). The results highlighted that, in fatigue stages, swimmers tend to increase their propulsive continuity, corresponding to a reduction of the non-propulsive lag time between the two arms' propulsive actions.

**Keywords:** Arm coordination, biomechanics, fatigue, front crawl, performance, swimming.

## INTRODUCTION

Technical performance in swimming has traditionally been evaluated through changes in velocity, stroke rate and stroke length. However, this approach does not provide specific information on the effectiveness of motor organization. Coordination emerge as a consequence of constraints imposed on action, reflecting a propensity towards self-organizing optimality in biological systems [1]. In the front crawl technique, the two arms move rhythmically in anti-phase inter-limb relationship, which reflects an intrinsic coordination mode [2], being one of the most important factors contributing to the generation of propulsive forces [3].

To assess the coordinative parameters in front crawl, Chollet *et al.* [4] proposed the Index of Coordination (IdC), a tool that measures the inter-arm lag time between propulsive phases. Following these authors, the three major patterns of arm coordination are the catch up, the superposition and the opposition modes, being the coordination employed by the swimmer determined by the relative contributions of each phase (entry/catch, pull, push and recovery) to the total duration of the arm stroke cycle.

The aim of the present study is to assess the IdC during a 200m front crawl maximal effort, as well as to understand its interplay with the stroking parameters. The relative contri-

bution of the arm stroke phases will also be assessed and discussed.

## METHODS

Six male competitive swimmers volunteered to participate in this study (20.3±2.8 years old, 69.4±4.8kg, 177.2±5.9cm, 183.3±7.0cm of arm span and 10.0±2.6% of fat mass). All participants signed a written informed consent in which the experimental protocol was described.

Swimmers were monitored in a 200m front crawl maximal test, when passing through a specific pre-calibrated space (calibration frame with dimensions of 3x3x3 m for the horizontal, vertical and lateral directions). Thirty points of calibration were used and the synchronisation of the images was obtained using a pair of lights visible in the field of view of each video camera.

Six stationary video cameras were used, being two above and four underwater (Sony® DCR-HC42E). One complete arm stroke cycle, without breathing, was analysed for each length of 50m, being assumed a six-beat kick synchronization. Test session took place in a 25m indoor pool, being used push starts in order to minimize the starting effect.

The video images were digitized with APASystem (Ariel Dynamics, USA) at a frequency of 50Hz, manually and frame by frame in order to have a more objective analysis. Twenty one anatomical reference points were used. Image coordinates were transformed to 3D object-space coordinates using the DLT algorithm and then filtered using a low pass digital filter of 6Hz. Each movement was then divided in

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four distinct phases defined as follows [4]: (i) entry/catch, which corresponds to the time between the entry of the hand into the water and the beginning of its backward movement; (ii) pull, corresponding to the time between the beginning of the backward movement of the hand and its entry into the plane vertical to the shoulder (initial part of the propulsion); (iii) push, the time between the positioning of the hand below the shoulder and its exit from the water and (iv) recovery, corresponding to the time between the exit of the hand and its next entry into the water.

The duration of each phase was measured with a precision of 0.02s and was expressed as a percentage of the duration of a complete stroke cycle. The duration of the propulsive and non-propulsive phases were the sum of pull and push, and of catch and exit phases, respectively.

The average horizontal velocity ( $v$ ) was assessed by dividing the displacement of the centre of mass in one stroke cycle for its total duration. Stroke rate (SR) was assessed through the inverse of its time duration, being stroke length (SL) considered the horizontal displacement of the centre of mass during a stroke cycle.

### Statistical Analysis

After the normality was checked, mean (SD) was computed for all variables. A one way repeated measures ANOVA, with Tukey post-hoc test was used to compare all the variables. Additionally, Pearson correlation coefficients were computed between IdC and the other biomechanical and coordinative parameters. The level of significance was set at  $p < 0.05$ .

### RESULTS

In Table 1 it is possible to observe the mean (SD) values of the general biomechanical parameters ( $v$ , SR and SL) and

of the coordinative organization parameters (IdC and stroke phases) for the four laps of the 200m front crawl test.

In Table 2 there are presented the coefficients of correlation between the IdC and all the other biomechanical and arm stroke phase variables.

### DISCUSSION

The purpose of this research was to study the behaviour of IdC through a 200m maximal front crawl effort and its relationship with the general biomechanical parameters. Moreover, as differences in the visual determination of IdC depends on the operator expertise [5], the assessment was done through digitization.

IdC staid in the catch-up mode during the whole effort. In the fourth lap it was observed an IdC increase possible due to fatigue (as previously observed in 100m race [6]). In this fatigue stages, swimmers tend to increase their propulsive continuity, as observed elsewhere [7]. However, it further reflected more time spent during the propulsive phase than greater force generation as the  $v$  and SL decreased in the last 50m of the 200m. These facts could be explained by the development of local muscular fatigue [8], reflecting a declining capacity to deliver power output [9]. Nonetheless, no changes were noticed for the SR, being the swimmers unable to increase it in order to compensate the SL decrease as suggested before (eg. [10]). These facts lead to an increase of the relative duration of the propulsive phases, reflecting the inability to generate enough propulsive force, as a consequence temporal structure changed [6].

Additionally, in the non-propulsive phases, IdC only was related with the entry/catch phase, implying that the relative time duration between the entry and the beginning of the pull phase has a great negative influence on the coordination

**Table 1. Mean (SD) Values of the Velocity, Stroke Rate, Stroke Length, Index of Coordination, Entry/Catch, Pull, Push, Recovery, Propulsive Phases and Non-Propulsive Phases in the four Laps of the 200m front Crawl**

	Velocity (m.s <sup>-1</sup> )	Stroke Rate (Stroke.min <sup>-1</sup> )	Stroke Length (m.Stroke <sup>-1</sup> )	Index of Coordination (%)	Entry/Catch (%)	Pull (%)	Push (%)	Recovery (%)	Propulsive (%)	Non-Propulsive (%)
1 <sup>st</sup> 50m	1.64 (0.04)	49.08 (3.04)	2.01 (0.15)	-13.1 (2.7)	37.7 (4.9)	23.1 (1.4)	14.1 (1.2)	25.1 (3.7)	37.2 (2.6)	62.8 (2.6)
2 <sup>nd</sup> 50m	1.48 (0.07) <sup>a</sup>	43.88 (3.18) <sup>a</sup>	2.03 (0.11)	-13.5 (3.8)	39.0 (5.1)	12.4 (1.6)	24.3 (3.4)	24.4 (3.1)	36.6 (4.0)	63.4 (4.0)
3 <sup>rd</sup> 50m	1.46 (0.05) <sup>a</sup>	44.34 (2.45) <sup>a</sup>	1.98 (0.12)	-13.9 (3.2)	39.3 (5.1)	12.4 (2.1)	23.8 (1.9)	24.5 (3.1)	36.2 (3.7)	63.8 (3.7)
4 <sup>th</sup> 50m	1.40 (0.08) <sup>a,b,c</sup>	44.33 (2.37) <sup>a</sup>	1.89 (0.15) <sup>b</sup>	-11.7 (3.9) <sub>a,b,c</sub>	37.8 (5.2)	13.5 (2.9)	24.9 (4.7)	23.8 (2.4)	38.4 (4.3) <sub>b,c</sub>	61.6 (4.3) <sub>b,c</sub>

<sup>a, b, c</sup> Significantly different from the first, second and third laps, respectively ( $p < 0.05$ ).

**Table 2. Correlation's Matrix Obtained Between Index of Coordination and Velocity, Stroke Rate, Stroke Length, Entry/Catch Phase, Pull Phase, Push Phase, Recovery, Propulsive Phases and Non-Propulsive Phases**

	Velocity (m.s <sup>-1</sup> )	Stroke Rate (Stroke.min <sup>-1</sup> )	Stroke Length (m.Stroke <sup>-1</sup> )	Entry/Catch (%)	Pull (%)	Push (%)	Recovery (%)	Propulsive (%)	Non-Propulsive (%)
Index of coordination (%)	ns	ns	ns	-0.78	0.54	0.78	ns	0.97	-0.97

mode, which should be diminished specially under fatigue conditions.

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