

*Original article (full paper)*

## **Longitudinal intra- and inter-individual variability in young swimmers' performance and determinant competition factors**

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**Abstract**—The main purpose of this study was to follow-up the intra- and inter-individual variability of young swimmers' performance and determinant factors over two competitive seasons. Thirty young swimmers (14 boys:  $12.33 \pm 0.65$  years-old; 16 girls:  $11.15 \pm 0.55$  years-old) were followed-up throughout two consecutive seasons (seven evaluation moments). Performance (100m freestyle), anthropometric, kinematic, hydrodynamic and efficiency features were evaluated. A gender and skill-level effect was observed. Boys improved in a higher amount (%) comparing to girls. Overall, swimmers in skill-level 2 (both genders) presented a higher intra-individual variability. Performance and anthropometrics showed a significant inter-individual variability in most moments, but hydrodynamics, kinematics and efficiency did not. Within each skill-level hydrodynamics, kinematics and efficiency were the variables that showed a high inter-individual variability. As a gender and skill-level effect was noticed in an age-group of young swimmers, coaches and practitioners should put the focus in specific and customized training plans for each skill-level of swimmers.

**Keywords:** young swimmers, seasons' variations, efficiency, stroke mechanics, anthropometrics

**Resumo**—“Análise longitudinal da variabilidade intra- e inter-individual da performance e fatores determinantes em nadadores jovens.” O objetivo principal do estudo foi acompanhar a variabilidade intra- e inter-individual da performance e dos seus fatores determinantes de nadadores jovens durante duas temporadas competitivas. Trinta nadadores jovens (14 nadadores:  $12.33 \pm 0.65$  anos; 16 nadadoras:  $11.15 \pm 0.55$  anos) foram avaliados ao longo das duas épocas (7 momentos de avaliação). Foi avaliada a performance (100m livres), e variáveis antropométricas, cinemáticas, hidrodinâmicas e de eficiência. Foi observado um efeito do sexo e do nível competitivo. Os nadadores melhoraram em maior quantidade (%) do que as nadadoras. Os nadadores no nível competitivo 2 (ambos os sexos) apresentaram uma intra-variabilidade superior. A performance e as variáveis antropométricas apresentaram uma inter-variabilidade significativa na maior parte dos momentos de avaliação, ao contrário das variáveis hidrodinâmicas, cinemáticas e de eficiência. Dentro de cada nível competitivo as variáveis hidrodinâmicas, cinemáticas e de eficiência foram as que apresentaram uma variabilidade inter-individual superior. Como foi verificado um efeito do sexo e do nível competitivo, treinadores e praticantes devem colocar o foco em treinos específicos e personalizados para cada grupo de nadadores de acordo com o nível competitivo.

**Palavras-chave:** nadadores jovens, variações sazonais, eficiência, mecânica da braçada, antropometria

**Resumen**—“Análisis longitudinal de la variabilidad intra- y inter-individual del rendimiento y sus determinantes en nadadores jóvenes.” El objetivo principal del estudio fue el seguimiento de la variabilidad intra- e inter-individual del rendimiento y sus factores determinantes de nadadores jóvenes en dos temporadas competitivas. Treinta nadadores jóvenes (14 niños:  $12.33 \pm 0.65$  años; 16 niñas:  $11.15 \pm 0.55$  años) fueron seguidos a lo largo de dos temporadas competitivas (7 momentos de evaluación). Se evaluó el rendimiento (100m estilo libre), e características antropométricas, cinemáticas, hidrodinámicas e la eficiencia. Se observó un efecto del sexo e del nivel de habilidad. Los niños mejoraron en una cantidad superior (%) en comparación con las niñas. En general, los nadadores de nivel de habilidad 2 (los dos sexos) presentaron una mayor variabilidad intra-individual. El rendimiento y la antropometría mostraron una variabilidad inter-individual significativa en la mayoría de los momentos, lo mismo no ocurrió con la hidrodinámica, la cinemática y la eficiencia. Dentro de cada nivel de habilidad, la hidrodinámica, la cinemática y la eficiencia fueron las variables que mostraron una alta variabilidad inter-individual. Como se ha observado un efecto de sexo e nivel de habilidad, entrenadores y practicantes deben poner el foco en los planes de formación específicos y personalizados para cada nivel de habilidad de los nadadores.

Palabras clave: nadadores jóvenes, variaciones estacionales, eficiencia, mecánica de la brazada, antropometría

## Introduction

Competitive swimming is a multifactorial sport that performance is determined by several factors (Barbosa *et al.*, 2010). Changes in anthropometric features influence biomechanical profile, this last ones affect energy profile and; hence the performance in both young (Morais *et al.*, 2012; Saavedra, Escalante & Rodríguez, 2010) and elite/adult swimmers (Barbosa *et al.*, 2010). Follow-up studies also have reported that anthropometric traits had an effect on performance and in several stroking parameters of young swimmers within and between seasons of training (Lätt *et al.*, 2009a; 2009b).

Earlier research was based on the universal perspective, that is, mean data is reported and analyzed. Mean data express individual changes that are shared by every subject. It is assumed a non-variance between subjects, or if this is identified, considered as being random error or noise in the dataset. Dynamical systems on movement patterns report that movement variability is driven by the interaction of the several sources of constraints (i.e., independent variables) on action leading to the uniqueness of system dynamics for a particular performer under a specific task (Davids, Glazier, Araújo, & Bartlett, 2003). Recent research suggested that each subject should be seen as a unique individual, where a complex and dynamical athlete-environment relationship exists (Philips, Davids, Renshaw, & Portus, 2010). Some authors report a specific and customized path in the development and maintenance of expert athletic performance (Durand-Bush & Salmela, 2002). Therefore, individual perspective of data analysis should be a priority in sports, including swimming.

There are a few papers about variability in swimming and mainly with to adult/elite cross-sectional research (Bideault, Herault, & Seifert, 2013; Vantorre, Seifert, Fernandes, Vilas-Boas, & Chollet, 2010). Individual changes drift away from the average main trend very often. High intra-individual variability in energetic measures was observed for elite swimmers through consecutive seasons of training (Anderson, Hopkins, Roberts, & Pyne, 2006; Costa *et al.*, 2013). However, to the best of our knowledge no longitudinal research was carried out with young swimmers based on this framework (i.e., a two-year follow-up, and analyzing both

intra and inter-variability). The only exception is the study of Minghelli and Castro (2006), that analyzed individual trends (mainly for kinematics) but for a shorter period of time (5 months).

Most follow-up and intervention programs reported data for pooled sample, for anthropometric or kinematic (Lätt *et al.*, 2009a) and hydrodynamics (Marinho *et al.*, 2010) disregarding the intra- and inter-individual variability. Therefore, performance research should give a step forward towards this type of research framework. Moreover, the variability of other determinant variables such as the body surface areas (such as hand, feet and trunk), intra-cyclic swimming velocity ( $dv$ ) and arm's propelling efficiency ( $\eta_p$ ) variables remains inexistent.

The aim of this study was to assess the intra- and inter-individual variability of young swimmers' performance and its determinant factors within and between seasons according to gender and skill level. It was hypothesized an improvement of the performance and likewise of its determinant factors for each gender and skill level. Most skilled swimmers would present a higher intra- and a lower inter-variability.

## Methods

### Participants

Fourteen boys (7 in high-skill level 1:  $12.83 \pm 0.37$  years of age, and  $294.4 \pm 40.0$  FINA points at SCM 100m freestyle; 7 in average-skill level 2:  $11.83 \pm 0.37$  years of age, and  $166.2 \pm 17.5$  FINA points at SCM 100m freestyle) and sixteen girls (8 in high-skill level 1:  $11.42 \pm 0.49$  years of age, and  $334.3 \pm 39.5$  FINA points at SCM 100m freestyle; 8 in average-skill level 2:  $10.83 \pm 0.37$  years of age, and  $229.1 \pm 33.9$  FINA points at SCM 100m freestyle) in Tanner stages 1-2 by self-report were evaluated. Sample includes age-group national record holders, national champions and other swimmers that are part of a national talent ID scheme. The swimmers had at the baseline  $3.40 \pm 0.56$  years of training experience (total number of training sessions: 1830 in two seasons; training sessions per week:  $5.09 \pm 0.87$ ; average volume per session:  $4.86 \pm 0.97$  km) and participating on regular basis in regional and national level competitions.

Coaches, parents and/or guardians and also the athletes gave their consent for participation on this study. All procedures were in accordance to the Helsinki Declaration regarding Human research. The University Institutional Review Board also approved the study design.

### Study design

A longitudinal research design was carried out. The repeated and subsequent measurements throughout time can be represented by a dataset of three-dimensional axis:

$$\eta_p = \left[ \left( \frac{v \cdot 0.9}{2\pi \cdot SF \cdot l} \right) \cdot \frac{2}{\pi} \right] \cdot 100 \quad (1)$$

where  $ij$  represent the axis,  $N$  represents the number of subjects (i.e.,  $N=30$ ),  $M$  represents the variables (i.e. anthropometric, kinematic, efficiency and hydrodynamic variables) and  $T$  represents the time measurements (seven evaluation moments over two consecutive seasons; i.e. two consecutive years). The first season evaluations occurred: M1 - 4 weeks after the beginning of the first season (first competition); M2 - in the middle of the first season (24 weeks after the beginning); M3 - in the end of the first season (38 weeks after the beginning of the first season. A 10 weeks interval occurred between the end of the first and the beginning of the second one. In the second season: M4 - immediately before the beginning of the second season (baseline); M5 - 4 weeks after the beginning of the second season (first competition); M6 - in the middle of the second season (24 weeks after the beginning) and; M7 - in the end of the second season (38 weeks after the beginning). Data collection procedures were carried out always under the same conditions in all evaluation moments (e.g. the same swimming pool, lane, time of day).

### Performance data collection

The official short course 100-m freestyle race (i.e. 25m length swimming pool) was selected as performance outcome. The time gap between the races and data collections took no longer than 15-days.

### Anthropometric data collection

For all measurements swimmers were asked to wear only a textile swimsuit and a cap. Body surface areas were measured with digital photogrammetry (Morais *et al.*, 2012). A 2D calibration frame and swimmers' dominant hand and foot were scanned with a copy machine (Xerox 4110, Norwalk, Connecticut, USA) to measure the hand surface area (HSA) and foot surface area (FSA) with specific software (Universal Desktop Ruler, v3.3.3268, AVPSOft, USA) (ICC: HSA=0.98; FSA=0.96). As for the trunk transverse surface area (TTSA; ICC=0.96) swimmers were photographed with a digital camera (DSC-T7, Sony, Tokyo, Japan) in the transverse plane from

above simulating the streamlined gliding position.

Body mass (BM) and height (H) were measured with a digital weighting scale (SECA, 884, Hamburg, Germany) and a digital stadiometer (SECA, 242, Hamburg, Germany) respectively. Arm span (AS) and chest perimeter (CP) were measured with an anthropometric tape (RossCraft, Canada). Arm span was measured with swimmers standing on the upright position, arms and fingers fully extended laterally abducted at a 90° angle. The distance between the tip of the third fingertip of each hand was measured (ICC=0.97). The CP was measured with the swimmers simulating the streamlined gliding position (ICC=0.96).

### Kinematic and efficiency data collection

Both kinematics and efficiency were assessed during the same trials. Swimming velocity ( $v$ ), stroke length (SL), stroke frequency (SF) and  $dv$  were selected as kinematic parameters. As for efficiency estimators, stroke index (SI) and  $\eta_p$  were selected. Swimmers performed three maximal freestyle swim trials of 25m with push-off start (30 minutes of recovery between bouts).

Kinematic data was collected with a speedo-meter (Swim speedo-meter, Swimsportec, Hildesheim, Germany). A 12-bit resolution acquisition card (USB-6008, National Instruments, Austin, Texas, USA) was used to transfer data (sampling rate at 50Hz) to a software customized by our group (LabVIEW® interface, v.2009) (Barbosa *et al.*, 2013). Data were exported to a signal processing software (AcqKnowledge v.3.5, Biopac Systems, Santa Barbara, USA) and filtered with a 5Hz cut-off low-pass 4<sup>th</sup> order Butterworth filter. Swimming velocity ( $v$ ,  $m \cdot s^{-1}$ ) was computed in the middle 15m as  $v=d/t$ . Two expert evaluators measured the stroke frequency (SF,  $cycles \cdot min^{-1}$ ) with a frequency counter during three consecutive strokes (ICC=0.98) and afterwards converted to Hz. Stroke length was computed as  $SL=v/SF$  (Craig & Pendergast, 1979). Speed fluctuation was computed as (Barbosa *et al.*, 2010):

$$dv = \frac{\sqrt{\sum_i (v_i - \bar{v})^2 F_i / n}}{\sum_i v_i F_i / n} \quad (2)$$

Where  $dv$  is the speed fluctuation (dimensionless),  $v$  is the mean velocity ( $m \cdot s^{-1}$ ),  $v_i$  is the instant velocity ( $m \cdot s^{-1}$ ),  $F_i$  is the absolute frequency and  $n$  is the number of observations. Stroke index was calculated as the product of SL and  $v$  ( $SI=SL \cdot v$ ) (Costill *et al.*, 1985). The  $\eta_p$  was estimated as (Zamparo, Pendergast, Mollendorf, Termin, & Minetti, 2005):

$$\eta_p = \left[ \left( \frac{v \cdot 0.9}{2\pi \cdot SF \cdot l} \right) \cdot \frac{2}{\pi} \right] \cdot 100 \quad (3)$$

Where  $\eta_p$  is the propelling efficiency (%),  $v$  is the velocity ( $m \cdot s^{-1}$ ), SF is the stroke frequency (Hz) and  $l$  is the distance between shoulder and tip of the 3<sup>rd</sup> finger during the insweep (m).

## Hydrodynamic data collection

Velocity Perturbation Method was used to estimate the active drag ( $D_a$ ) and the coefficient of active drag ( $C_{Da}$ ) (Kolmogorov & Duplisheva, 1992). Swimmers performed two maximal trials of 25m at front crawl with push-off start (one trial with and other without carrying on the perturbation device). Two expert evaluators with stopwatches measured the trials between the 11<sup>th</sup> and 24<sup>th</sup> meter (ICC=0.97) (Marinho *et al.*, 2010). Both evaluators walked with the swimmer to have a perfect line of sight when the swimmer passed the specific point of measurement. Active drag and  $C_{Da}$  were estimated respectively as (Kolmogorov & Duplisheva, 1992):

$$D_a = \frac{D_b v_b v^2}{v^3 - v_b^3} \quad (4)$$

$$C_{Da} = \frac{2 \cdot D_a}{\rho \cdot S \cdot v^2} \quad (5)$$

Where  $D_a$  is the swimmers' active drag at maximal velocity (N),  $D_b$  is the resistance of the perturbation buoy computed from the manufacturer's calibration of the buoy-drag characteristics and its velocity (N),  $v_b$  and  $v$  are the swimming velocities with and without the perturbation device ( $\text{m} \cdot \text{s}^{-1}$ ),  $C_{Da}$  is the active drag coefficient (dimensionless),  $\rho$  is the water density (assumed to be  $1000 \text{ kg} \cdot \text{m}^{-3}$ ),  $v$  is the velocity ( $\text{m} \cdot \text{s}^{-1}$ ) and  $S$  (or TTSA as reported in the anthropometrics sub-section) is the swimmers' projected frontal surface area ( $\text{cm}^2$ ).

## Statistical analysis

Normality and homocedasticity assumptions were analyzed with the Kolmogorov-Smirnov and Levene tests, respectively. Intra-individual data variation was analyzed with ANOVA three-ways for all selected variables (time, gender and skill effects and interactions) followed by the Bonferroni post-hoc test ( $p \leq .05$ ). Intra-individual differences between moments within and between seasons ( $\Delta$ , in %) were also calculated for each skill-level (skill-level 1: highest; skill-level 2: average). Total eta square ( $h^2$ ) was selected as effect size index and interpreted as: (i) without effect if  $0 < h^2 \leq 0.04$ ; (ii) minimum if  $0.04 < h^2 \leq 0.25$ ; (iii) moderate if  $0.25 < h^2 < 0.64$  and; (iv) strong if  $h^2 > 0.64$ .

The *t*-student test for independent sample was used to assess inter-individual variability between skill-level in each gender ( $p \leq .05$ ). The Cohen's Kappa, delimited by the percentiles 33, 66 and 100 was used to detect the boys and girls' inter-variability within each sports level. Kappa plus 95% confidence interval was computed with the Longitudinal Data Analysis software (v.3.2, Dallas, USA). The qualitative interpretation was done as (Landis & Koch, 1977): excellent if  $K \geq 0.75$ ; (ii) moderate if  $0.40 \leq K < 0.75$  and; (iii) low if  $K < 0.40$  based on the stability (i.e. higher stability means lower inter-individual variability).

## Results

Overall data presented a significant time effect for all variables but the SF (Table 1). Also a significant gender effect was showed for most variables, except the  $C_{Da}$ ,  $dv$  and  $\eta_p$ . The skill-level effect showed the same trend, except for the FSA,  $C_{Da}$ , SF and  $dv$ .

Table 1. Data variation (ANOVA 3-way) during the two competitive seasons for total group of swimmers.

	Time Effect			Gender Effect			Skill level Effect			Time x Gender x Skill level Interaction		
	<i>F</i>	<i>p</i>	$\eta^2$	<i>F</i>	<i>p</i>	$\eta^2$	<i>F</i>	<i>p</i>	$\eta^2$	<i>F</i>	<i>p</i>	$\eta^2$
<b>BM [kg]</b>	125.96	< .001	0.95	10.29	.004	0.20	13.78	.001	0.27	0.41	.74	0.003
<b>H [cm]</b>	136.90	< .001	0.78	12.80	.001	0.25	11.48	.002	0.22	0.87	.40	0.004
<b>AS [cm]</b>	143.99	< .001	0.78	20.67	< .001	0.34	12.72	.001	0.21	0.78	.45	0.004
<b>CP [cm]</b>	96.98	< .001	0.77	7.52	.01	0.14	16.99	< .001	0.33	0.35	.80	0.002
<b>TTSA [cm<sup>2</sup>]</b>	24.72	< .001	0.47	4.45	.04	0.10	11.68	.002	0.27	0.27	.86	0.005
<b>HSA [cm<sup>2</sup>]</b>	171.48	< .001	0.84	31.85	< .001	0.43	13.90	.001	0.18	0.22	.87	0.001
<b>FSA [cm<sup>2</sup>]</b>	79.53	< .001	0.74	24.03	< .001	0.43	3.60	.069	0.06	0.33	.74	0.003
<b>SF [Hz]</b>	1.51	.21	0.04	10.71	.003	0.28	1.14	.29	0.03	1.94	.11	0.06
<b>SL [m]</b>	42.80	< .001	0.59	4.71	.03	0.08	23.78	< .001	0.42	0.77	.52	0.01
<b>v [m·s<sup>-1</sup>]</b>	68.50	< .001	0.70	44.77	< .001	0.49	16.79	< .001	0.18	0.58	.63	0.005
<b>dv [dimensionless]</b>	2.78	.05	0.09	1.65	.21	0.05	0.31	.57	0.01	0.54	.63	0.01
<b><math>D_a</math> [N]</b>	17.82	< .001	0.39	7.82	.01	0.18	7.23	.01	0.17	0.09	.96	0.002
<b><math>C_{Da}</math> [dimensionless]</b>	11.35	< .001	0.26	0.53	.47	0.01	0.007	.93	0.00	0.60	.65	0.01
<b><math>\eta_p</math> [%]</b>	30.79	< .001	0.50	1.36	.25	0.04	5.89	.02	0.17	0.60	.65	0.009
<b>SI [m<sup>2</sup>·s<sup>-1</sup>]</b>	63.22	< .001	0.68	29.36	< .001	0.31	33.50	< .001	0.36	0.42	.74	0.004
<b>Perf@100free [s]</b>	106.92	< .001	0.69	35.87	< .001	0.33	40.97	< .001	0.38	1.23	.30	0.007

BM – body mass; AS – arm span; H – height; CP – chest perimeter; TTSA – trunk transverse surface area; HSA – hand surface area; FSA – foot surface area;  $D_a$  – active drag;  $C_{Da}$  – active drag coefficient; SF – stroke frequency; SL – stroke length;  $v$  – swimming velocity;  $dv$  – speed fluctuation;  $\eta_p$  – propelling efficiency; SI – stroke index; Perf – performance;  $\eta^2$  – effect size.



Performance improved significantly for the two genders in both skill-levels between initial and final moment (Figure 1). For both genders, the swimmers in the skill-level 2 presented a higher intra-individual variability (i.e. higher amount of improvement) between consecutive moments (within season) and also in homologous ones (between seasons) (Table 2A,B). Anthropometrics presented a similar trend as most variables increased significantly between initial and final moment. The skill-level 2 swimmers were the ones with the highest variability (Figure 2, Table 2 A,B). Hydrodynamics also increased between initial and final moment but not significantly for both consecutive and homologous moments (Figure 2, Table 2A,B). Boys' skill-level 2 presented the highest intra-individual variability (within and between seasons) in comparison to boys' skill-level 1 (Table 2A). As for the girls, an inverse trend was observed in consecutive moments (within) but similar in homologous ones (Table 2B). Kinematics and efficiency improved between initial and final moment, being significant only for the swimming velocity. For both boys and girls, the skill-level 2 presented the highest amount of intra-individual variability. Overall for all variables, swimmers (both genders) in skill-level 2 presented a higher intra-variability.

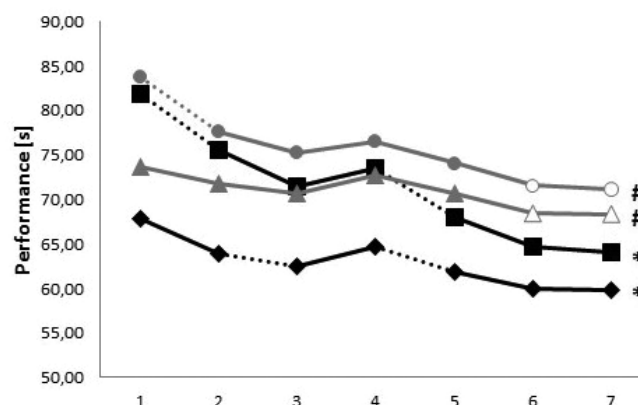


Figure 1. Performance variability along the two seasons. Black solid line (♦)(■) – boys sports level 1 and 2 respectively; grey solid line (▲)(●) – girls sports level 1 and 2 respectively; dot parts within solid line means significant differences ( $p \leq .05$ ) between moments for each sports level; white background in the marker – no-significant differences ( $p > .05$ ) between sports level within each gender; PERF – performance@100free; \* and # after each sports level line – significant differences ( $p \leq .05$ ) between initial (1) and final moment (7) for boys and girls, respectively.

Table 2A. Intra-individual differences (%) between consecutive and homologous moments for boys (1: high-skill level vs 2: average-skill level).

		Δ for consecutive moments within seasons						Δ and p for homologous moments between seasons						
		M1vsM2	M2vsM3	M3vsM4	M4vsM5	M5vsM6	M6vsM7	M1vsM7	ΔM1vsM5	p	ΔM2vsM6	p	ΔM3vsM7	p
										M1vsM5		M2vsM6		M3vsM7
BM	Boys 1	1.48	2.81	3.30	0.70	1.46	-0.78	8.77	8.13	< .001	8.08	.007	4.69	.02
	Boys 2	3.89	3.47	5.43	0.62	3.89	1.41	17.44	12.81	.008	12.86	< .001	11.00	.003
H [%]	Boys 1	1.24	0.60	1.40	0.12	0.69	0.39	4.36	3.33	.04	2.78	.41	2.57	.56
	Boys 2	1.14	0.61	3.24	0.44	1.38	0.60	7.24	5.37	.004	5.61	.002	5.59	.002
AS [%]	Boys 1	1.67	0.67	0.50	0.64	1.12	0.48	4.99	3.45	.07	2.90	.18	2.72	.13
	Boys 2	1.48	1.42	2.07	1.04	1.71	1.36	8.76	5.89	.009	6.12	.002	6.05	.001
CP [%]	Boys 1	2.19	2.07	0.31	2.75	0.51	0.28	7.95	7.20	.004	2.09	.01	3.83	.25
	Boys 2	3.27	1.90	1.32	2.11	1.45	-0.16	9.61	8.40	.006	6.64	.01	4.69	.07
HSA	Boys 1	4.00	2.93	3.37	3.10	2.86	2.11	17.17	12.88	< .001	11.81	.004	10.96	.04
	Boys 2	4.53	1.96	4.30	3.47	2.94	1.46	17.33	13.60	.006	12.11	.003	11.64	.01
FSA	Boys 1	4.76	1.35	1.57	2.18	2.85	2.13	14.21	9.62	.08	7.79	.06	8.49	.09
	Boys 2	6.58	1.85	2.85	1.39	3.38	2.97	17.68	12.08	.13	9.23	.003	10.25	.001
TTSA	Boys 1	5.42	-2.31	4.18	4.39	4.20	4.63	20.58	13.17	.17	10.67	1	16.03	.41
	Boys 2	11.19	-4.43	3.99	4.00	3.26	5.06	22.27	15.39	.02	7.37	.99	15.12	.37
D <sub>a</sub> [%]	Boys 1	-1.92	1.06	-4.62	8.69	-7.99	-3.64	19.86	29.12	.76	20.80	1	12.37	1
	Boys 2	0.94	6.19	-22.02	27.89	20.39	-24.95	38.30	23.90	1	50.54	.03	25.40	.98
C <sub>Da</sub> [%]	Boys 1	-4.47	-2.19	12.86	-11.85	-0.44	-16.48	-0.30	10.23	1	12.88	1	-2.45	1
	Boys 2	-19.14	-1.94	-7.21	25.80	7.40	-28.48	9.82	6.44	1	42.89	< .001	13.63	1
SF [%]	Boys 1	6.94	1.06	-1.60	-3.58	4.73	0.09	8.13	3.17	1	0.97	1	0.05	1
	Boys 2	1.55	2.10	-4.03	-1.59	8.65	-4.29	4.02	-1.21	1	5.39	1	-0.09	1
SL [%]	Boys 1	-31.81	15.96	8.13	3.15	-1.47	1.28	5.86	5.99	.60	24.71	.21	10.90	1
	Boys 2	-26.64	19.83	12.52	2.98	-4.30	4.04	17.62	17.43	.50	29.18	.11	15.50	.22
v [%]	Boys 1	-27.13	16.66	7.00	-0.15	3.17	1.20	9.77	5.64	.14	25.41	.12	10.69	1
	Boys 2	-23.86	25.31	4.69	2.28	4.74	0.36	21.10	16.45	1	34.19	.005	11.75	.06
dv [%]	Boys 1	16.68	-30.37	-9.44	8.46	-11.56	-2.49	-1.15	8.42	1	-42.17	1	-9.07	1
	Boys 2	7.47	-20.55	2.99	-9.94	8.15	-1.58	1.98	-11.10	1	-12.06	1	5.39	1
SI [%]	Boys 1	-73.93	27.60	13.40	2.93	2.05	2.23	14.96	11.27	.06	41.78	.14	19.10	1
	Boys 2	-67.62	38.58	16.56	5.45	0.44	4.23	32.93	28.90	.41	52.10	.01	25.35	.04
η <sub>p</sub> [%]	Boys 1	-37.17	16.24	7.48	2.51	-2.44	-1.96	-4.21	0.12	1	23.12	.32	5.87	1
	Boys 2	-28.13	21.90	7.49	0.79	2.02	-8.05	8.46	11.74	1	29.62	.31	5.13	1
Perf@100free [%]	Boys 1	-6.16	-2.41	3.52	-4.72	-3.07	-0.20	-13.39	-9.78	.02	-6.67	.53	-4.38	1
	Boys 2	-8.25	-5.96	2.70	-8.00	-5.05	-1.00	-27.80	-20.58	.009	-16.88	.001	-11.44	.002

Table 2B. Intra-individual differences (%) between consecutive and homologous moments for girls (1: high-skill level vs 2: average-skill level).

		Δ for consecutive moments within seasons						Δ and P for homologous moments between seasons						
		M1vsM2	M2vsM3	M3vsM4	M4vsM5	M5vsM6	M6vsM7	M1vsM7	ΔM1vsM5	p M1vsM5	ΔM2vsM6	p M2vsM6	ΔM3vsM7	p M3vsM7
BM [%]	Girls 1	-0.18	2.86	3.69	1.51	1.77	0.26	9.71	7.85	< .001	9.58	.009	7.14	.07
	Girls 2	1.39	4.59	3.94	1.70	3.07	2.41	16.00	11.20	.02	12.65	.01	10.66	.03
H [%]	Girls 1	1.08	0.34	1.15	0.54	0.39	0.34	3.80	3.09	.002	2.41	.01	2.41	.08
	Girls 2	1.30	1.14	1.63	0.61	1.12	0.43	6.09	4.62	< .001	4.43	.002	3.76	.004
AS [%]	Girls 1	1.60	1.13	0.54	0.57	0.54	0.26	4.57	3.80	.02	2.76	.01	1.90	.09
	Girls 2	2.45	1.28	1.02	0.76	2.01	0.65	7.92	5.41	.001	4.99	.001	4.39	.001
CP [%]	Girls 1	2.26	1.60	0.63	2.58	1.56	-0.56	7.89	6.92	.008	6.26	.01	4.22	.06
	Girls 2	2.85	1.84	0.82	3.02	2.48	0.80	11.31	8.30	.008	7.91	.03	6.95	.04
HSA [%]	Girls 1	5.80	1.86	2.64	1.93	2.15	2.19	15.51	11.70	.007	8.35	.001	8.61	.01
	Girls 2	6.09	2.19	2.23	3.46	1.61	2.23	16.64	13.26	.009	9.20	.004	9.25	.002
FSA [%]	Girls 1	4.24	5.53	3.50	1.40	1.56	1.56	16.46	13.75	.11	11.50	.01	7.80	.02
	Girls 2	6.20	2.95	3.25	2.75	1.72	1.17	16.92	14.43	.05	10.26	.02	8.64	.02
TTSA [%]	Girls 1	6.91	-4.04	3.02	2.98	3.53	3.00	15.89	10.22	1	5.72	1	11.75	.59
	Girls 2	7.76	1.53	4.31	0.07	2.50	6.29	22.14	14.71	.006	8.69	1	13.33	.26
D <sub>a</sub> [%]	Girls 1	-8.19	8.75	-4.88	43.23	-20.97	-6.42	43.80	50.58	.009	47.08	.12	42.88	.05
	Girls 2	-5.14	13.96	-2.95	34.17	26.38	-104.57	37.82	50.24	.003	63.67	.04	30.96	1
C <sub>Da</sub> [%]	Girls 1	-21.91	11.71	22.85	17.11	-25.10	-9.05	38.60	52.74	.001	48.17	.14	42.69	.11
	Girls 2	-34.26	2.11	8.37	28.82	26.27	-106.57	26.18	33.96	.04	54.27	.08	32.98	1
SF [%]	Girls 1	-3.02	-1.40	-1.58	3.05	-0.44	2.26	-0.71	-2.23	1	0.52	1	3.95	1
	Girls 2	4.37	-1.00	4.88	-3.85	-4.78	0.89	2.50	5.50	1	-3.09	1	-1.42	1
SL [%]	Girls 1	-38.39	20.33	15.69	-3.63	6.09	-3.31	10.52	8.20	1	37.25	< .001	16.95	.09
	Girls 2	-18.41	15.80	5.67	5.17	8.50	-1.36	21.57	15.35	.20	32.38	.01	17.98	.21
v [%]	Girls 1	-38.14	18.26	14.34	0.70	6.03	-0.72	13.52	8.47	.24	36.63	< .001	19.41	.27
	Girls 2	-12.90	17.75	9.85	2.34	4.97	-0.35	23.86	19.98	.18	31.65	.001	16.35	.02
dv [%]	Girls 1	-9.36	-11.87	-10.84	-6.95	-13.03	-11.54	-62.35	-38.41	1	-39.32	1	-37.48	.13
	Girls 2	3.14	1.56	-6.08	-7.11	-12.04	-18.41	-36.15	-9.15	1	-18.46	1	-46.55	.49
SI [%]	Girls 1	-93.96	32.66	25.21	-2.67	11.77	-3.61	23.36	16.11	.23	59.87	< .001	32.03	.07
	Girls 2	-39.90	29.23	13.46	7.72	12.94	-1.87	38.95	31.11	.08	52.54	.003	30.54	.06
η <sub>p</sub> [%]	Girls 1	-36.05	20.25	16.31	-5.08	10.89	-7.44	13.33	9.50	.64	40.68	.001	18.79	.50
	Girls 2	-21.08	17.94	5.76	3.17	14.89	-13.62	17.64	13.93	.08	37.52	.005	13.46	.56
Perf@100free [%]	Girls 1	-2.66	-1.72	2.91	-2.82	-3.40	-0.14	-7.77	-4.17	.22	-4.91	.14	-3.30	1
	Girls 2	-8.01	-3.05	1.71	-3.44	-3.60	-0.61	-17.85	-13.11	.01	-8.40	.006	-5.91	.21

BM – body mass; AS – arm span; H – height; CP – chest perimeter; TTSA – trunk transverse surface area; HSA – hand surface area; FSA – foot surface area; D<sub>a</sub> – active drag; C<sub>Da</sub> – active drag coefficient; SF – stroke frequency; SL – stroke length; v – swimming velocity; dv – speed fluctuation;  $\eta_p$  – propelling efficiency; SI – stroke index; Perf – performance; M – moment;  $\Delta$  – delta value; p – significant value; % – percentage.

Performance data showed a significant inter-individual variability between skill-levels within both genders in most moments (Figure 1). Anthropometric features also showed a significant inter-individual variability except in the last moments stage of the second season (M6 and M7) (Figure 2). The FSA presented no-significant inter-individual variability in all moments for both genders. As for hydrodynamics, kinematics and efficiency the main trend was the no-significant inter-individual variability in both genders and skill-levels. The exception was the v that presented significant inter-individual variability between skill-levels in several

moments, mainly for the boys (Figures 2 and 3). Overall, an inverse trend was found for anthropometrics (significant) and remaining domains (no-significant) between skill-levels for both genders.

Performance presented a moderate ( $0.40 \leq K < 0.75$ ) inter-individual variability in each gender and skill-level, except for boys in the skill-level 2 (high,  $K = 0.24$ ). Hydrodynamics, kinematics and efficiency showed a high inter-individual variability in both genders and skill-levels (except the SF for the boys' skill-level 1: low,  $K = 0.66$ ). Overall, it seems that a high inter-individual variability exists within each skill-level.

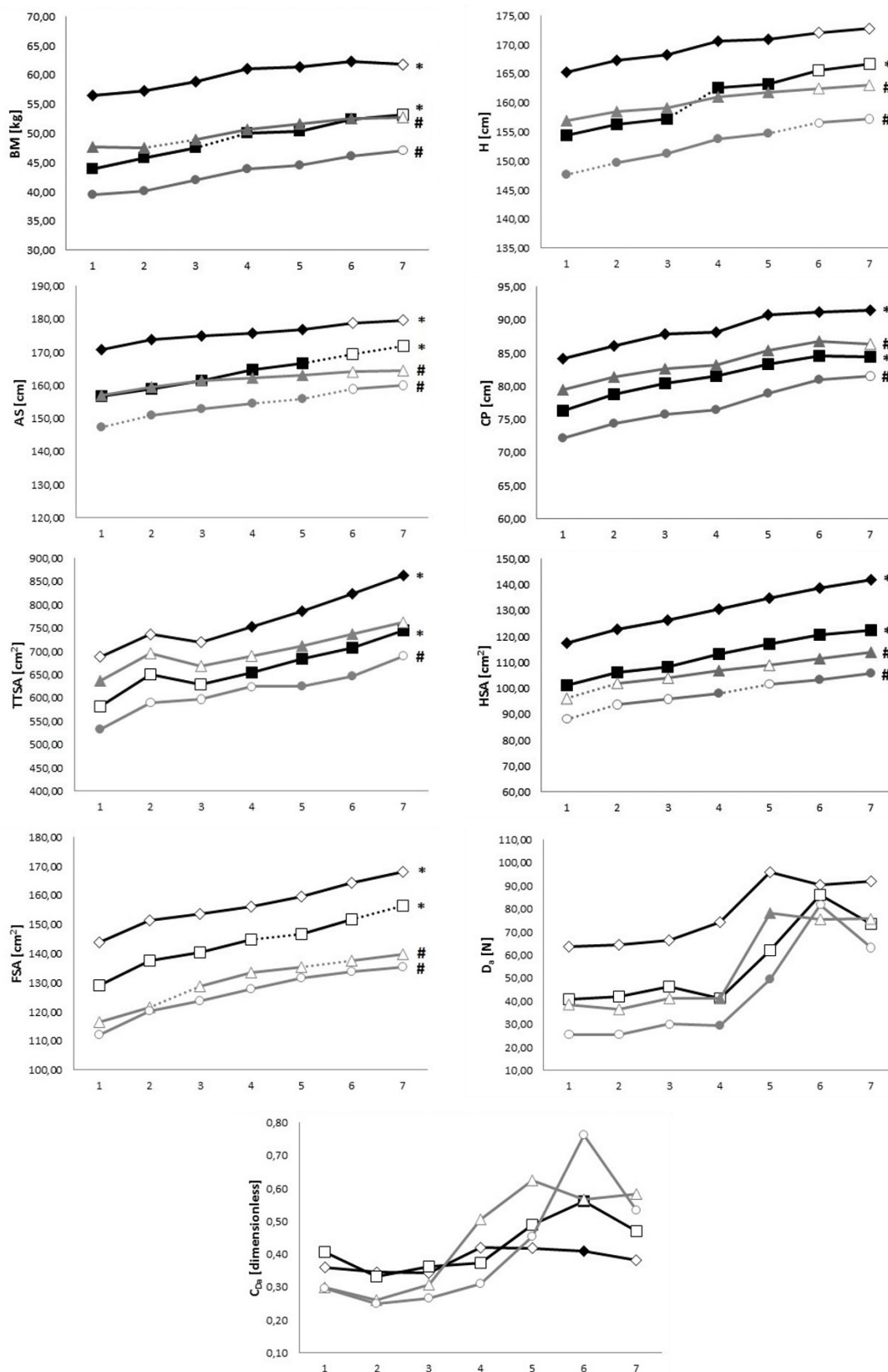


Figure 2. Anthropometric and hydrodynamic variability along the two seasons. Black solid line (♦) (■) – boys sports level 1 and 2 respectively; grey solid line (▲) (●) – girls sports level 1 and 2 respectively; dot parts within solid line means significant differences ( $p \leq .05$ ) between moments for each sports level; white background in the marker – no-significant differences ( $P > 0.05$ ) between sports level within each gender; BM – body mass; AS – arm span; H – height; CP – chest perimeter; TTSA – trunk transverse surface area; HSA – hand surface area; FSA – foot surface area; D<sub>a</sub> – active drag; C<sub>da</sub> – active drag coefficient; \* and # after each sports level line – significant differences ( $p \leq .05$ ) between initial (1) and final moment (7) for boys and girls, respectively.

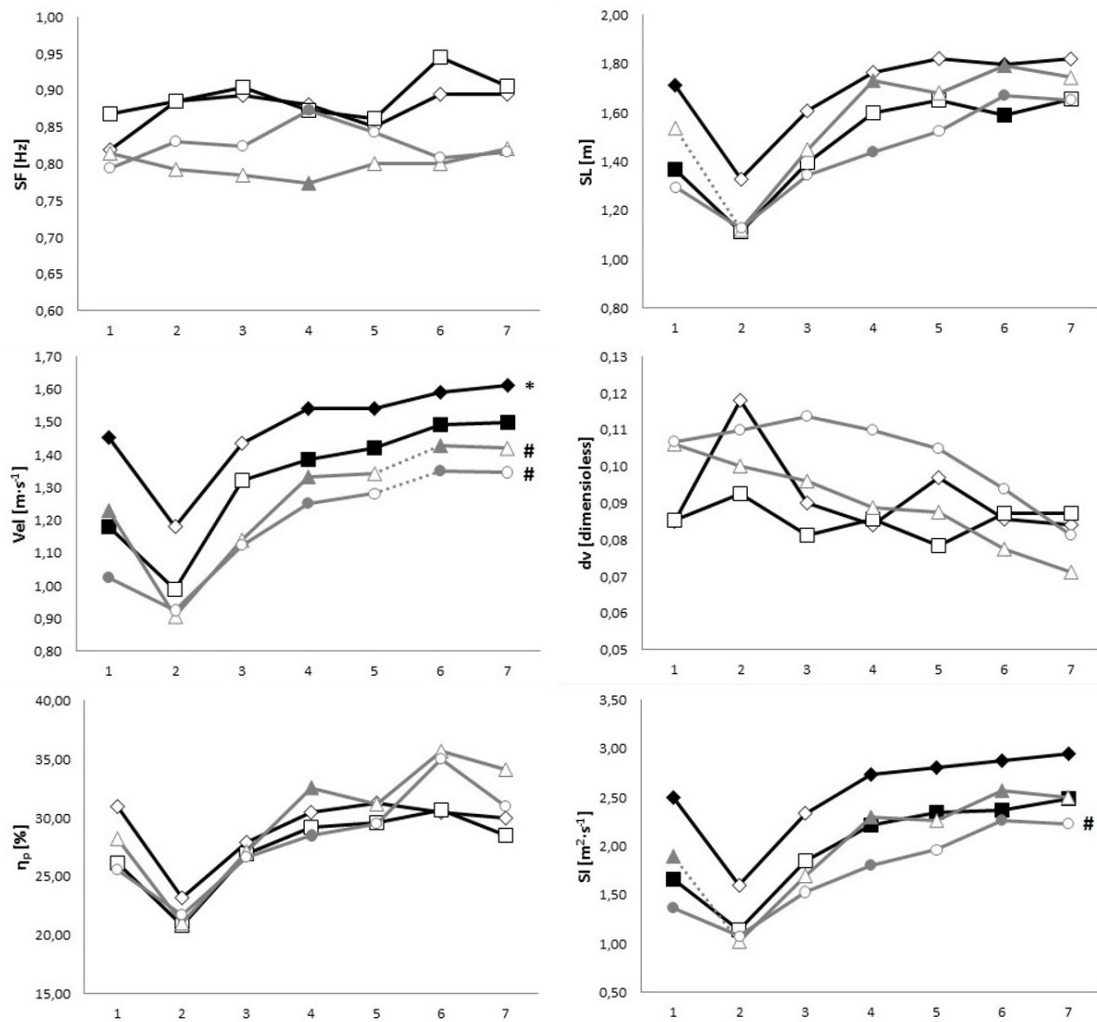


Figure 3. Kinematic and energetic variability along the two seasons. Black solid line (♦) (■) – boys sports level 1 and 2 respectively; grey solid line (▲) (●) – girls sports level 1 and 2 respectively; dot parts within solid line means significant differences ( $p \leq .05$ ) between moments for each sports level; white background in the marker – no-significant differences ( $p > .05$ ) between sports level within each gender; SF – stroke frequency; SL – stroke length; v – swimming velocity; dv – speed fluctuation;  $\eta_p$  – propelling efficiency; SI – stroke index; \* and # after each sports level line – significant differences ( $p \leq .05$ ) between initial (1) and final moment (7) for boys and girls, respectively.

## Discussion

The aim of this study was to assess the intra- and inter-individual variability of young swimmers' performance and its determinant factors within and between seasons according to gender and skill-level. Main findings were the significant gender and skill-level (both genders) effects. Swimmers in skill-level 2 presented a higher intra-individual variability in comparison to skill-level 1. Overall, a significant inter-individual variability between skill-levels (both genders) was found for performance and anthropometrics but not for hydrodynamics, kinematics and efficiency.

### Intra-individual variability

Performance showed a significant improvement between first (M1) and last (M7) evaluations in both genders and skill-levels. Previous studies also pointed out a performance improvement for young swimmers during two consecutive years (Lätt *et al.*, 2009a;

2009b; Tella, Llana, Madera, & Navarro, 2002). However, these studies plotted all swimmers only by gender and did not have into account the hypothetical differences between swimmers of the same gender. Present data shows that swimmers in the same age-group have different rates of performance enhancement (Figure 1, Table 2A,B). Regarding the gender gap, boys improved more sharply their performance than girls when comparing homologous skill-levels (skill-level 1 boys vs. girls: -13.39% vs. -7.77%; skill-level 2 boys vs. girls: -27.80% vs. -17.85%). And swimmers in skill-level 2 (both genders) showed a higher intra-individual variability in comparison to the ones in skill-level 1. The delayed maturation in boys in comparison to girls may explain the gender gap and therefore the higher amount of performance improvement. And it might be speculated that swimmers in skill-level 2 (both genders) were also in a less mature phase, increasing their chances to enhance the performance.

All anthropometric variables (i.e. lengths and body surfaces) increased between M1 and M7 for both genders' skill-levels, and most of them significantly (Figure 2, Table 2A,B). Young



swimmers, as any other children, experience physical changes as part of their normal biological development. Body mass, height, and therefore, limbs' lengths and areas are some of the anthropometric features that change with growth (Malina & Bouchard, 1991). Overall, growth rate was similar or higher in boys than in girls. These data suggested that boys were in an accelerated development stage, while girls have eventually experienced such biological development before. Literature is consensual that girls overcome maturation two years earlier than boys (Malina & Bouchard, 1991). However between skill-levels, within each gender, swimmers presented differences between them (i.e. a high intra-individual variability). Swimmers in skill-level 2 were characterized by a higher intra-individual variability (increase) in comparison to their skill-level 1 counterparts. These differences highlight the existent variability even in an age-group of swimmers, suggesting that each swimmer has a specific developmental rate.

Regarding hydrodynamics, mixed results were obtained. Both  $D_a$  and  $C_{Da}$  increased between M1 and M7 in both genders, except the  $C_{Da}$  for boys and girls in skill-level 1 (decrease). Unchanged hydrodynamics was reported for eight weeks of training at the beginning of a season (Marinho *et al.*, 2010). The main aim of this general period of preparation was to build-up aerobic capacity and aerobic power, enhancing swimming technique. However, one week of drill training with specific visual and kinaesthetic feedbacks, was enough to decrease  $C_{Da}$  in pubescent swimmers (Havriluk, 2006). So, hydrodynamic enhancement is more related to technical ability than to energetic build-up. Indeed swimmers in skill-level 1 (both genders) did decrease their  $C_{Da}$  (boys: -0.30%; girls: -0.71%). During the two-year assessment, the swimmers training included technical drills to enhance their hydrodynamic profile (i.e., optimizing their body and segments position while swimming). Nevertheless our data shows that those technical drills had a higher contribution to the fastest swimmers (skill-level 1) than on their counterparts in skill-level 2. These differences in technical ability parameters also highlight the intra-individual variability in an age-group of swimmers within each gender.

Overall, kinematics and efficiency increased (enhanced) between M1 and M7, but only the  $v$  showed a significant increase. The improvement of young swimmers' swimming velocity between two major competitions was reported as being related to SL increases and SF decreases (Tella *et al.*, 2002). This SL-SR relationship is a result of growth (e.g. height, arm span, hands and feet dimensions). However, present data showed an increase in the SF for most groups (except girls' skill-level 1). It seems that at these early ages swimmers use both SF and SL to improve swimming velocity and therefore the performance. Skill-level 2 swimmers presented a higher amount of improvement. As these swimmers also showed a higher intra-individual variability in the anthropometrics, this highlights the influence of anthropometrics features in stroke mechanics. Nevertheless, kinematic and efficiency features presented a no-linear fashion way. In M2 swimmers were submitted to a heavy training period to build-up other determinant domains of performance (e.g. energetics). E.g. as we can learn from the swimmers sub-section, volume training per session was  $4.86 \pm 0.97$  km. Hence, in M2, volume would be

close to the upper limit of this confidence interval. However, one might not consider that this kind of energetic training comes with no downside. Stroke mechanics seems to impair due to it (for both genders' skill-levels), even so, performance in M2 was not affected for all conditions.

### *Inter-individual variability*

Based on paired comparisons, a significant inter-individual variability was showed between skill-levels in both genders along the two seasons for the performance and most of the anthropometric features (except for the FSA, all conditions). On the other hand, hydrodynamics, kinematics and efficiency did not present the same trend. For both genders' skill-levels a no-significant inter-individual variability was observed in most moments. Yet the  $v$  and the SI did show a significant inter-individual variability between skill-levels (mainly on boys) in most of the moments in the two seasons. Therefore it can be stated that an inter-individual variability do exist within an age-group of young swimmers, especially for the anthropometrics and some variables responsible for the stroke mechanics (i.e.,  $v$  and SI). Silva *et al.* (2013) showed that pubertal swimmers (in both genders) do have higher standards in variables related to stroke mechanics (e.g.,  $v$  and SL). However, literature does not report young swimmers' variability within an age-group or other kind in longitudinal researches. Previous studies (Lätt *et al.*, 2009a, 2009b; Tella *et al.*, 2002) assumed that swimmers in the same age-group share the same development pattern and that variance might be a residual error. However, new trends in swimming research suggest that each athlete has a unique development rate (Philips *et al.*, 2010). In fact present data highlight that a swimmers' age-group is characterized by a significant inter-individual variability namely in anthropometric features,  $v$  (kinematics) and SI (efficiency). Indeed swimmers in skill-level 1 (both genders) were characterized by higher body dimensions,  $v$  and SI and hence a higher performance.

Inter-individual variability based on Cohen's Kappa quantifies the partial position of a swimmer against remaining contenders within a skill-level. A higher variability indicates that there are several changes in the partial position of the swimmers throughout the time-frame under analysis (Costa *et al.*, 2012). Overall, performance showed a moderate ( $0.40 \leq K < 0.75$ ) and anthropometrics a high stability ( $K \geq 0.75$ ; i.e. a low inter-individual variability) for both genders' skill-levels. Contrarily, for hydrodynamics, kinematics and efficiency a high inter-individual variability was observed ( $K < 0.40$ ). These findings are of major importance as it also highlights the existent variability for technical ability patterns within a group of swimmers with similar characteristics. Especially in swimmers that are still suffering growth and maturation processes that influence the stroke mechanics. Moreover, each athlete should be seen as a unique individual and therefore one might consider that each one "chooses" their path to enhance performance. Nowadays adult/elite research highlight that these individual changes should not be considered as residual variances (Costa *et al.*, 2013). This perspective comes along with the state of the art about motor control and motor learning, that in terms of human movement,

newer theories of movement control do not view variability in movements as error (i.e. dynamical systems theory). So, performance research should give a step forward towards this type of research framework.

## Conclusion

We conclude that within an age-group of young swimmers a gender and skill-level effect was identified. Overall in both genders, swimmers in skill-level 2 presented a higher intra-individual variability. During the two seasons the performance and the anthropometric features were the ones presenting a significant inter-individual variability between skill-levels and also a moderate (performance) to high (anthropometrics) inter-individual variability within each skill-level. Therefore swimmers in the same age-group do differ between them, hence practitioners and coaches should design customized training plans for each swimmer and put more focus on individual and dynamic analysis frameworks.

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