

Tracking the performance, energetics and biomechanics of international versus national level swimmers during a competitive season

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Abstract The purpose of this study was to track and compare the changes of performance, energetic and biomechanical profiles of international (Int) and national (Nat) level swimmers during a season. Ten Portuguese male swimmers (four Int and six Nat level subjects) were evaluated on three different time periods (TP₁, TP₂, TP₃) of the 2009–2010 season. Swimming performance was assessed based on official time's lists of the 200-m freestyle event. An incremental set of 7 × 200 m swims was applied to assess the energetic and biomechanical data. Measurements were made of: (1) velocity at the 4 mmol of lactate levels (V4), stroke index at V4 (SI@V4) and propelling efficiency at V4 ($\eta_p@V4$), as energetic estimators; (2) stroke length at V4 (SL@V4) and stroke frequency at V4 (SF@V4), as biomechanical variables. The results demonstrated no significant variations in all variables throughout the season.

The inter-group comparison pointed out higher values for Int swimmers, with statistical differences for the 200 m performance in all time periods. Near values of the statistical significance were demonstrated for the SI@V4 in TP₁ and TP₃. The tracking based on *K* values was high only for the SI@V4. It is concluded that a high stability can be observed for elite swimmers performance, energetic and biomechanical profiles throughout a single season. Int swimmers are able to maintain a higher energetic and biomechanical capacity than Nat ones at all times. The SI@V4 may be used as an indicator of performance variation.

Keywords Performance · Elite swimmers · Biophysics profile · Tracking · Freestyle

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Introduction

The identification of the variables that can predict the swimming performance is one of the main topics in swimming science. Special emphasis has been given to the physiological/energetics and biomechanical assessment as determinant domains to achieve high levels of swimming performance (e.g. Barbosa et al. 2008).

At the moment, few papers investigated longitudinal data concerning the changes in energetics and/or biomechanical variables. However, most of them focused their attention in a single domain (energetics or biomechanical one). According to the literature, significant improvements in maximal oxygen consumption (Magel et al. 1975; Houston et al. 1981; Termin and Pendergast 2000), velocity at 4 mmol L⁻¹ of lactate levels (Reis and Alves 2006; Robertson et al. 2010) and lactate tolerance (Sharp et al. 1984; Pyne et al. 2001) were observed due to the

training process. Changes in the biomechanical variables were observed as well. Throughout full training seasons, significant improvements were reported for the stroke length (SL) (Hay and Guimarães 1983), stroke frequency (SF) (Huot-Marchand et al. 2005) and no significant changes were found for both SL and SF (Mingheli and Castro 2006). Few other studies investigated at the same time both domains (Wakayoshi et al. 1993; Termin and Pendergast 2000; Anderson et al. 2008; Latt et al. 2009a, 2009b). Decreases in blood lactate concentrations related to swimming velocity were observed after 6 months of aerobic training (Wakayoshi et al. 1993). A training program based on the stroke frequency–velocity relationship can improve the swimmer's biomechanical and energetic profile enhancing the swimming performance (Termin and Pendergast 2000). When monitoring changes in test measures for 3.6 ± 2.5 years, the stroke frequency at 4 mmol L^{-1} of blood lactate concentration (SF@V4) for males ($r = 0.41$) and the skinfolds for females ($r = -0.53$), showed to be reliable variables to predict the Breaststroke performance (Anderson et al. 2008). For two consecutive seasons, it was reported that the stroke index (SI) best correlates to the 400-m freestyle performance for both young male and female swimmers (Latt et al. 2009a, b).

Moreover, it is known that swimmers from different competitive levels present different energetic and biomechanical profiles. Several cross-sectional studies have already compared different cohort groups. High-level swimmers are more economical (energy cost at a given velocity) and efficient than lower level ones (Toussaint 1990; Fernandes et al. 2006). Moreover, the SL (Seifert et al. 2007) and the propelling efficiency (η_p) (Toussaint 1990) are higher in elite swimmers, while the active drag (Pendergast et al. 2006) is lower than other competitive levels. International swimmers present higher SI values when compared to the nationals (Sánchez and Arellano 2002).

To the best of our knowledge, no study until now tried to deal with the question if the same type of training load induces different responses according to the swimmers competitive level during a full competitive season. Therefore, the aim of this research was to: (1) track the stability and the changes of performance, energetic and biomechanical profiles from international and national level swimmers during a full competitive season; (2) compare the performance, energetic and biomechanical profiles between both cohort groups. It was hypothesized that (1) there was a performance enhancement throughout the competitive season, along with a high stability in energetic and biomechanical variables and; (2) there are different energetic and biomechanical profiles comparing international versus national level swimmers.

Methods

Subjects

Ten Portuguese male swimmers of international (Int) and national (Nat) level, volunteered to serve as subjects. It was considered that Int level swimmers are the ones ($N = 4$; 20 ± 3.40 years old; 1.83 ± 0.08 m of height; 73.15 ± 10.13 kg of body mass; $21.76 \pm 1.53 \text{ kg.m}^{-2}$ of body mass index; 1.90 ± 0.09 m of arm span and; 112.39 ± 4.22 s of personal record in the 200 m freestyle event) with regular participation on international meetings in the previous season, representing the Portuguese National Swimming Team. It was defined that Nat level swimmers are ($N = 6$; 20 ± 3.25 years old; 1.77 ± 0.05 m of height; 72.93 ± 6.34 kg of body mass; $23.19 \pm 1.80 \text{ kg.m}^{-2}$ of body mass index; 1.85 ± 0.04 m of arm span and; 118.43 ± 2.21 s of personal record in the 200-m freestyle event) the ones with regular presence in the national championships.

Study design

The swimmers were studied in three occasions during the 2009–2010 calendar: (1) December 2009 (TP₁); (2) March 2010 (TP₂) and; (3) June 2010 (TP₃). The TP₁, TP₂ and TP₃ coincided with the participation in the Winter Short Course National Championships, Winter Long Course National Championships and Summer National Championships, respectively. In the time period between tests the swimmers completed a full training preparation. Swim training generally consisted of a mixture of low, moderate and intense training characterized by: (1) training units (tu) (TP₁: $8.88 \pm 0.64 \text{ tu week}^{-1}$; TP₂: $9.00 \pm 0.85 \text{ tu week}^{-1}$; TP₃: $8.73 \pm 0.90 \text{ tu week}^{-1}$); (2) volume (TP₁: $44.53 \pm 6.45 \text{ km week}^{-1}$; TP₂: $43.87 \pm 5.86 \text{ km week}^{-1}$; TP₃: $43.61 \pm 8.25 \text{ km week}^{-1}$); (3) low aerobic tasks (TP₁: $39.06 \pm 3.11 \text{ km week}^{-1}$; TP₂: $38.41 \pm 2.82 \text{ km week}^{-1}$; TP₃: $39.14 \pm 3.61 \text{ km week}^{-1}$); (4) intensity corresponding to their aerobic capacity (TP₁: $2.35 \pm 0.95 \text{ km week}^{-1}$; TP₂: $2.16 \pm 0.96 \text{ km week}^{-1}$; TP₃: $1.55 \pm 0.41 \text{ km week}^{-1}$); (5) intensity corresponding to their aerobic power (TP₁: $1.41 \pm 0.38 \text{ km week}^{-1}$; TP₂: $1.25 \pm 0.38 \text{ km week}^{-1}$; TP₃: $1.00 \pm 0.28 \text{ km week}^{-1}$); (6) lactate tolerance training (TP₁: $0.76 \pm 0.26 \text{ km week}^{-1}$; TP₂: $0.80 \pm 0.18 \text{ km week}^{-1}$; TP₃: $0.89 \pm 0.15 \text{ km week}^{-1}$); (7) intensity of maximal lactate power (TP₁: $0.27 \pm 0.05 \text{ km week}^{-1}$; TP₂: $0.29 \pm 0.08 \text{ km week}^{-1}$; TP₃: $0.50 \pm 0.35 \text{ km week}^{-1}$) and; (8) velocity training (TP₁: $0.68 \pm 0.22 \text{ km week}^{-1}$; TP₂: $0.95 \pm 0.17 \text{ km week}^{-1}$; TP₃: $0.54 \pm 0.16 \text{ km week}^{-1}$). Technical training was performed during the low aerobic tasks, including practicing technical drills.

On each occasion the swimmers completed an intermittent set of 7×200 m front crawl with increasing velocity as described elsewhere (e.g. Barbosa et al. 2008). The velocities and increments were chosen, so that swimmers would attain their best performance on the last trial. The starting velocity was set at a speed, which represented a low training pace, approximately 0.3 m s^{-1} less than the swimmer's best performance. After each successive 200-m swim, the velocity was increased by 0.05 m s^{-1} until exhaustion and/or until the swimmer could no longer swim at the predetermined pace. A 30-s resting period was used between trials to collect blood samples. Underwater pace-maker lights (GBK-Pacer, GBK Electronics, Aveiro, Portugal), on the bottom of a 50-m swimming pool, were used to control the swimming velocity and to help the swimmers keep an even pace along each lap and step. In addition, elapsed time for each trial was measured with a chronometer to control the swimmer's velocity.

Performance data collection

Swimming performance was assessed based on times lists of the 200-m freestyle event during official long course competitions from local, regional, national and/or international level. The time gap between energetic plus biomechanical assessment and swimming performance was made in less than 2 weeks.

Energetics data collection

Energetics assessment included the analysis of the velocity at 4 mmol L^{-1} of blood lactate concentration ($V4$) as an aerobic capacity indicator, the stroke index and the propelling efficiency at the same velocity ($SI@V4$ and $\eta_p@V4$, respectively) as swim efficiency estimators. To determine the $V4$, capillary blood samples were collected from the ear lobe to determine the lactate concentrations $[La^-]$ with an auto-analyzer (YSI 1500 L, Yellow Springs, OH, USA). Collecting process occurred during the 30-s resting period between trials of the intermittent protocol. The auto-analyzer calibration was initially performed with several standard lactate solutions (2, 4, 8 and 16 mmol L^{-1}). The $[La^-]$ values allowed the individual $V4$ measurement interpolating the average lactate value (4 mmol L^{-1}), with the exponential curve of lactate/speed. The $SI@V4$, considered as one of the swimming stroke efficiency indexes, was adapted and computed as (Costill et al. 1985):

$$SI@V4 = V4 \times SL@V4 \quad (1)$$

where $SI@V4$ is the stroke index at $V4$ ($\text{m}^2 \text{ c}^{-1} \text{ s}^{-1}$), $V4$ is the 4 mmol L^{-1} lactate concentration velocity (m s^{-1}) and the $SL@V4$ is the stroke length at $V4$ (m). The $\eta_p@V4$ was also estimated as being (Zamparo et al. 2005):

$$\eta_p@V4 = \left(\frac{V4 \times 0.9}{2\pi \times SF@V4 \times l} \right) \cdot \frac{2}{\pi} \quad (2)$$

where $V4$ is the 4 mmol L^{-1} lactate concentration velocity (m s^{-1}), the $SF@V4$ is the stroke frequency at $V4$ (Hz) and l is the arm's length (m). The l is computed trigonometrically measuring the arm's length and considering the average elbow angles during the insweep of the arm pull as reported by Zamparo (2006). Equation 2 is properly speaking the Froude efficiency. The difference between Froude and propelling efficiency is that the first one does not take into account the effect of the internal mechanical work to total mechanical work production. As reported by Zamparo et al. (2005), at the range of swim velocity verified in these swimmers, internal mechanical work is rather low and can be neglected. So, propelling efficiency becomes very similar to Froude efficiency.

Biomechanical data collection

For biomechanical assessment both stroke frequency at $V4$ and stroke length at $V4$ ($SF@V4$ and $SL@V4$, respectively) were measured. SF was obtained with a crono-frequency meter (Golfinho Sports MC 815, Aveiro, Portugal) from three consecutive stroke cycles, in the middle of each lap during each trial. Then, SF values were converted to International System Units (Hz). The $SF@V4$ was calculated by the interpolation of the SF value in the $V4$ by the curve SF -velocity. $SL@V4$ was estimated as being (Craig et al. 1985):

$$SL@V4 = \frac{V4}{SF@V4} \quad (3)$$

where $SL@V4$ is the stroke length at $V4$ (m), $V4$ is the 4 mmol L^{-1} lactate concentration velocity (m s^{-1}), and the $SF@V4$ is the stroke frequency at $V4$ (Hz).

Statistical procedures

Normality was determined by Shapiro–Wilk test. Since, the very low value of the N (i.e., $N < 30$) and the rejection of the null hypothesis (H_0) in the normality assessment, non-parametric procedures were adopted. Longitudinal assessment was made based on two approaches: (1) mean stability and; (2) normative stability. For mean stability, mean plus one standard deviation and quartiles were computed for each time period. Data variation was analyzed with Friedman test, as well the Wilcoxon signed-rank test to assess differences between time periods (TP_1 vs. TP_2 ; TP_1 vs. TP_3 ; TP_2 vs. TP_3). The differences in both cohort groups (Int vs. Nat level) were analyzed computing the Mann–Whitney U test. Normative stability was analyzed with the Cohen's Kappa (K) plus one standard deviation,

with a confidence interval of 95% as proposed by Costa et al. (2010a). The qualitative interpretation of K values was made according to Landis and Koch (1977) suggestion, where the stability is: (1) excellent if $K \geq 0.75$; (2) moderate if $0.40 \leq K < 0.75$ and; (3) low if $K < 0.40$. The Ranking Spearman correlation coefficient was also computed as another normative stability parameter. Qualitatively, stability was considered to be: (1) high if $r \geq 0.60$; (2) moderate if $0.30 \leq r < 0.60$ and; (3) low if $r < 0.30$, adapted from Malina (2001). All statistical procedures were conducted with SPSS software (v. 13.0, Apache Software Foundation, Chicago, IL, USA). However, the K value was computed with the Longitudinal Data Analysis software (v. 3.2, Dallas, USA). The level of statistical significance was set at $P \leq 0.05$.

Results

Figure 1 present the 200-m freestyle performance variation during the three consecutive time periods. No significant variations were verified throughout the season. Wilcoxon tests also demonstrated no significant differences between pair wise time periods. However, values with statistical significance were observed when comparing both cohort groups: TP₁ (Int200 m = 115.38 ± 4.33 s; Nac200 m = 121.43 ± 2.46 s; $P = 0.03$), TP₂ (Int200 m = 115.85 ± 3.12 s; Nac200 m = 121.25 ± 2.60 s; $P = 0.03$) and TP₃ (Int200 m = 115.18 ± 3.16 s; Nac200 m = 121.41 ± 3.02 s; $P = 0.02$).

Figure 2 presents the energetic variables variation throughout the competitive season. No significant variations were observed between pair wise time periods. The only exception was the comparison of Nat SI@V4 between TP₂ and TP₃ ($SI@V4_{TP2} = 3.78 \pm 0.26$ m² c⁻¹ s⁻¹; $SI@V4_{TP3} = 3.88 \pm 0.22$ m² c⁻¹ s⁻¹; $P = 0.05$). Very close to the statistical significance cut-off value adopted were also verified for Nat SI@V4 between the TP₁ and TP₂ ($SI@V4_{TP1} = 3.75 \pm 0.29$ m² c⁻¹ s⁻¹; $SI@V4_{TP2} = 3.78 \pm 0.26$ m² c⁻¹ s⁻¹; $P = 0.06$) and between TP₁ and TP₃ ($SI@V4_{TP1} = 3.75 \pm 0.29$ m² c⁻¹ s⁻¹; $SI@V4_{TP3} = 3.88 \pm 0.22$ m² c⁻¹ s⁻¹;

$c^{-1} s^{-1}$; $P = 0.07$). Significant differences were demonstrated for V4 when comparing both groups on TP₂ (IntV4 = 1.48 ± 0.03 m s⁻¹; NacV4 = 1.42 ± 0.06 m s⁻¹; $P = 0.05$). Remaining variables presented no significant values. However, once again, the SI@V4 on the TP₁ (IntSI@V4 = 4.12 ± 0.26 m² c⁻¹ s⁻¹; NacSI@V4 = 3.75 ± 0.29 m² c⁻¹ s⁻¹; $P = 0.06$) and TP₃ (IntSI@V4 = 4.22 ± 0.21 m² c⁻¹ s⁻¹; NacSI@V4 = 3.88 ± 0.22 m² c⁻¹ s⁻¹; $P = 0.07$) was very close to the statistical significance cut-off value.

Figure 3 presents the biomechanical parameters variation. Both variables presented no significant variations across the season and between time periods. No significant differences were also found comparing Int with Nat level swimmers. However, two trends can be observed. Nat swimmers increased both biomechanical variables while Int ones decreased SF@V4 and increased SL@V4.

Table 1 presents the relative changes (i.e. %) in performance, energetics and biomechanics throughout the season from TP₁ to TP₂, TP₂ to TP₃ and the overall time period. From the TP₁ to TP₂ the Int group presented decreases in the relative change for almost all variables. The only exception was the SF@V4 ($1.05 \pm 5.14\%$). On the other hand, the opposite trend was observed for Nat swimmers. From the TP₂ to TP₃ both cohort groups revealed increases in all variables. The SI@V4 presented the highest change during the overall season (IntSI@V4 = $2.70 \pm 5.98\%$; NatSI@V4 = $3.70 \pm 4.47\%$).

The K values for a 95% of confidence interval, which expresses the overall stability on competitive level tracks throughout the season, were rather low for the V4 ($K = 0.23 \pm 0.26$) and SL@V4 ($K = 0.39 \pm 0.26$). Moderate values were verified for the 200-m event ($K = 0.49 \pm 0.26$), SF@V4 ($K = 0.54 \pm 0.26$), and η_p @V4 ($K = 0.60 \pm 0.26$). Only the SI@V4 presented a high stability ($K = 0.80 \pm 0.26$).

Table 2 presents the Spearman correlation coefficient values for pair wise time periods throughout competitive season. Correlations were significant in almost all paired data ($P < 0.01$). The tracking values of 200 m freestyle performance revealed moderate–high stability ($0.56 \leq r \leq 0.88$).

Fig. 1 Variation of the 200-m freestyle performance during the competitive season. *Significant difference between Int and Nat swimmers performances (TP₁ $P = 0.03$; TP₂ $P = 0.03$; TP₃ = 0.02)

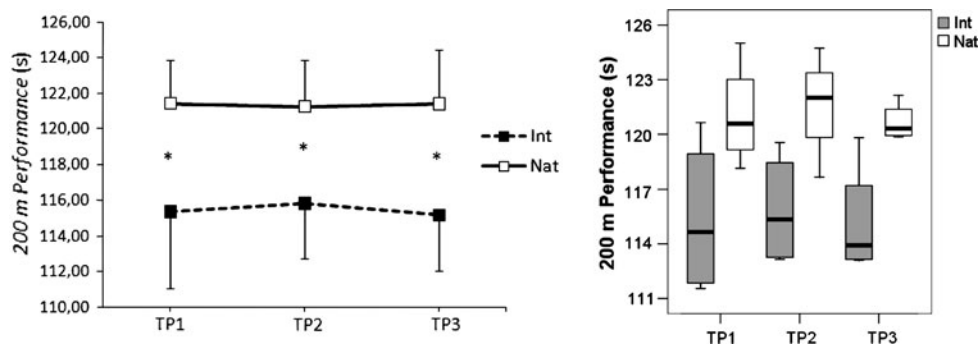
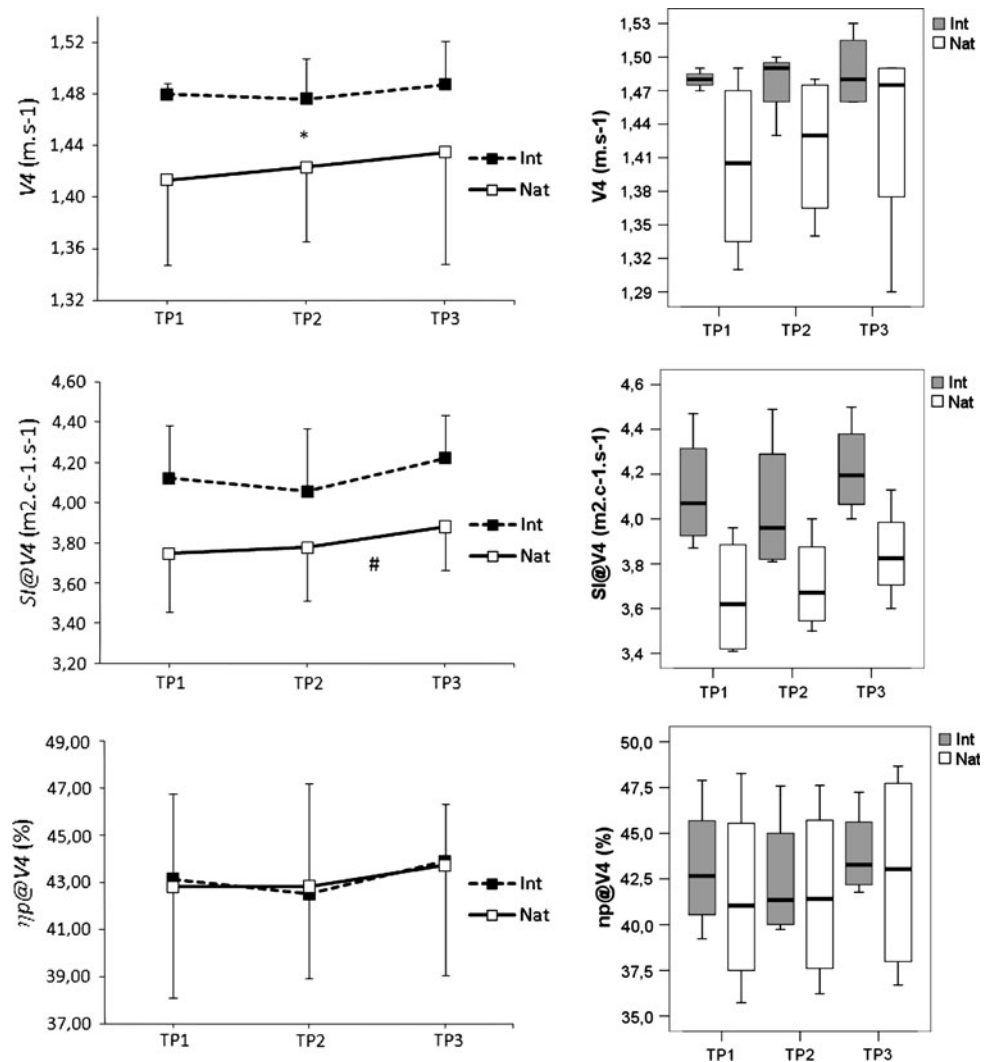


Fig. 2 Variation of energetic variables during the three time periods. *Significant difference from international and national level swimmers V4 (TP₂ $P = 0.05$). #Significant differences in Nationals SI@V4 between TP₂ and TP₃ ($P = 0.05$)



Both energetic and biomechanical values measured were also relatively high: SI@V4 ($0.77 \leq r \leq 0.95$), $\eta_p@V4$ ($0.76 \leq r \leq 0.93$), SF@V4 ($0.65 \leq r \leq 0.90$), SL@V4 ($0.65 \leq r \leq 0.92$). The only exception was the V4 with low–high stability ($0.33 \leq r \leq 0.82$).

Discussion

The purpose of this study was to track the changes in performance, energetic and biomechanical variables and to longitudinally compare those variables between Int and Nat level swimmers submitted to the same training load. No significant differences in performance, energetic and biomechanical variables were observed for both Int and Nat swimmers across the season. For all variables, the stability in such reduced time frame was high. Int performances, energetic and biomechanical values were on a regular basis higher than Nat ones, giving to the SI@V4 the importance as an indicator of performance variation.

Performance

Despite slight changes, the 200-m freestyle performance remained unaltered over the course of the study. A lack of, or small magnitude of improvement, has been already published in a couple of papers (Costill et al. 1991; Pyne et al., 2001). Due to the maximal external load and technical ability reached, Nat and Int swimmers have some difficulties in promoting huge improvements in a single season. For some cases, swimmers from this competitive level are trained to improve a few decimal or centesimal seconds per season or during an Olympic cycle (Costa et al. 2010a). That is the reason why from a statistical point of view it becomes difficult to verify significant differences. However, a couple of papers presented significant improvements in performance after some weeks of training (Mujika et al. 2002) or even, from a season to another (e.g. Mujika et al. 1995; Termin and Pendergast 2000; Trinity et al. 2008).

The Int swimmers performance declines ($0.48 \pm 3.57\%$) from TP₁ to TP₂ and thereafter improves ($0.57 \pm 1.16\%$)

Fig. 3 Variation of biomechanical parameters across the season

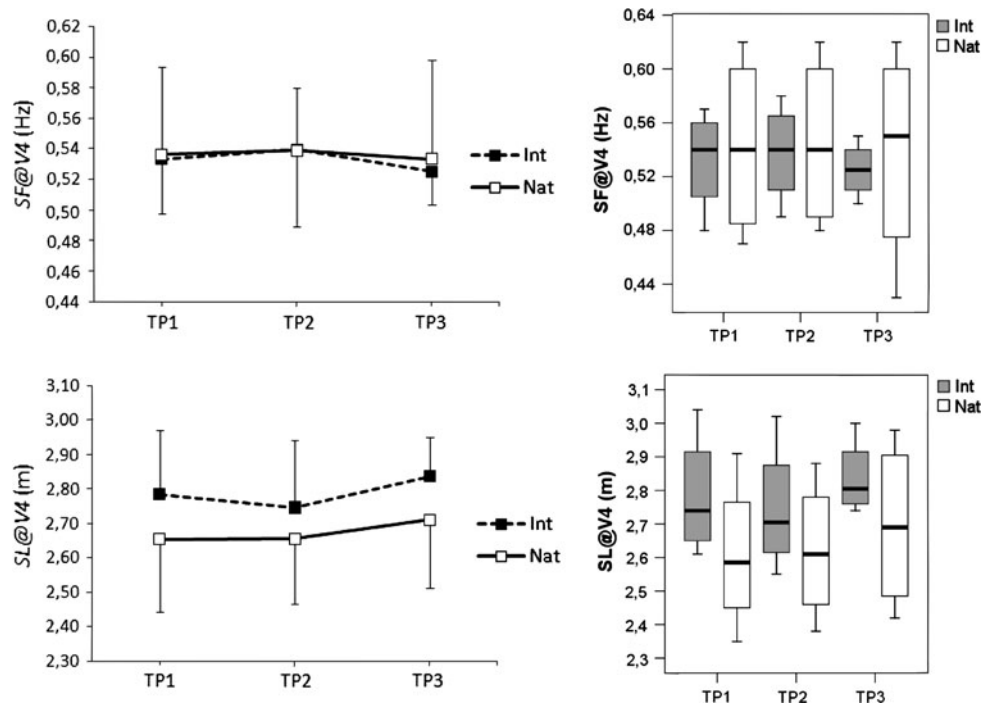


Table 1 Relative changes (%) in performance, energetic and biomechanical variables between time periods and for the overall competitive season

		Between evaluation moments (%)		Overall season (%)
		TP ₁ –TP ₂	TP ₂ –TP ₃	TP ₁ –TP ₃
200 m	Int	−0.48 ± 3.57	0.57 ± 1.16	0.09 ± 2.66
	Nat	0.15 ± 1.17	−0.19 ± 3.87	−0.04 ± 3.31
V4	Int	−0.25 ± 2.09	0.83 ± 4.41	0.58 ± 2.68
	Nat	0.75 ± 2.06	0.77 ± 3.08	1.52 ± 4.22
SI@V4	Int	−1.66 ± 2.03	4.36 ± 6.35	2.70 ± 5.98
	Nat	0.87 ± 2.63	2.83 ± 2.59	3.70 ± 4.47
η_p @V4	Int	−1.37 ± 3.24	3.52 ± 5.10	2.15 ± 4.45
	Nat	0.12 ± 1.47	2.17 ± 5.26	2.29 ± 6.56
SF@V4	Int	1.05 ± 5.14	−2.83 ± 7.21	−1.71 ± 4.49
	Nat	0.59 ± 2.45	−1.59 ± 8.30	−1.00 ± 10.11
SL@V4	Int	−1.37 ± 3.24	3.52 ± 5.10	2.15 ± 4.45
	Nat	0.12 ± 1.47	2.17 ± 5.26	2.29 ± 6.56

from TP₂ to TP₃. Declines in sprint performance were also observed after 6 weeks of training with an increased volume in collegiate swimmers (Costill et al. 1991). Literature suggests that swimming efforts from 30 s to 4 min require the contribution from both aerobic and anaerobic systems (Troup 1991). Recent findings confirmed 66% aerobic and 34% anaerobic contribution for the total 200-m event (Figueiredo et al. 2011). Aerobic fitness should be developed before more specific and high-intensity training such as aerobic power and lactate tolerance (Pyne et al. 2001). So, the middle of the season performance decline from TP₁ to TP₂ for Int swimmers can be related to a decrease in total volume of aerobic and anaerobic training, suggesting that periodization was

ineffective in developing the various aspects of both energetic pathways. However, the training load was not harmful for both cohorts. In the national level group, five swimmers were presenting better performances at all time periods. Only one swimmer did not demonstrate the same trend. Since a reduced sample size the performance median values are more informative than mean ones. In this sense, some given swimmer with a large variation regarding the mean data lead to the rejection of the null hypothesis. Thus, some caution should exist when interpreting some inferential data as for this case. Despite a relative change (values from TP₂ to TP₃ showed a decline, 0.19 ± 3.87%) from a qualitative point of view, most national level swimmers demonstrated better

Table 2 Interperiod Spearman correlation coefficients of performance, energetic and biomechanical variables measured in elite swimmers ($n = 10$) at the time periods of training

Variable	TP ₁ vs. TP ₂	TP ₂ vs. TP ₃	TP ₁ vs. TP ₃
200 m (s)	0.88**	0.56**	0.64*
V4 (m s ⁻¹)	0.82**	0.33	0.42
SI@V4 (m ² c ⁻¹ s ⁻¹)	0.95**	0.83**	0.77**
η_p @V4 (%)	0.93**	0.86**	0.76*
SF@V4 (Hz)	0.90**	0.65*	0.66*
SL@V4 (m)	0.92**	0.72*	0.65*

* $P < 0.05$ ** $P < 0.01$

performances. It appears that Nat swimmers are not affected in a similar way as Int ones. Despite the aerobic and anaerobic load reduction, the continuous training provides sufficient stimulus for a slight performance variation across the season in the Nat cohort.

The inter-group comparison pointed out a significant and higher Int performance for all time periods (TP₁ $P = 0.03$; TP₂ $P = 0.03$; and TP₃ $P = 0.02$). Having increased energetic and biomechanical profiles, it is obvious that Int performances tend to be higher. At the same time, those Int need to perform at high-level on a regular basis not to be sent out from the financial and training, control and evaluation of National Olympic project.

Energetics

Changes with no significant meaning were observed in V4 as well. Because the energetic capacity of elite swimmers is characterized by extreme values at the upper limits, tracking energetic variables in this population presents an extra-challenge (Davison et al. 2009). Despite the absence of statistical significance, these findings confirm earlier observations about variations in V4 after several months of aerobic training (Sharp et al. 1984; Wakayoshi et al. 1993; Pyne et al. 2001). The training induces muscle adaptations and improves the ability to produce energy aerobically (Madsen 1983). In TP₃ a slight decline in Int swimmer's V4 was observed. This can be explained by extreme aerobic fitness values reached in the middle of the season. Probably Int swimmers have already reached their personal aerobic peak at this point. In addition, the decrease in the total training volume at an intensity of their aerobic capacity in TP₃ may have contributed to this V4 declining. So, the performance variation in the final stage of the season seems to be mainly due to an improvement in the anaerobic fitness and technical factors. On the other hand, Nat swimmers were able to increase V4 at all time. As previously suggested, the aerobic training reduction throughout the season

was not harmful for this cohort and the continuous training provided sufficient stimulus to increase aerobic capacity.

Int swimmers presented higher values of V4 when compared to the Nat. Indeed, in the TP₂ significant differences were observed between both groups ($P = 0.05$). V4 represents a unique combination of SF@V4 and SL@V4 (Craig and Pendergast 1979). Having higher SF and lower SL, less skilled swimmers experience more difficulties in sustaining a maximal aerobic effort (Fernandes et al. 2006). That is the reason why elite swimmers have a better capacity to maximize their energy input than lower level ones (Fernandes et al. 2006).

SI@V4 and η_p @V4 are overall indicators of swimming efficiency. Both variables presented slight changes over the course of the study. SI@V4 has double effect from V4 (Costill et al. 1985). Slight and even non-meaningful changes in V4 and SL@V4 led to significant changes in SI@V4. Indeed, significant meaning ($P = 0.05$) was observed for the Nat SI@V4 from the TP₂ to TP₃. The higher time spent in low aerobic tasks related to technical training in the final stage of the season may explain this improvement in SI@V4 and η_p @V4, resulting in a performance enhancement in both groups. It appears that the high aerobic capacity reached earlier in the season, along with the time spent on practicing technical drills from TP₂ to TP₃ was determinant in increasing swimming efficiency. To the best of our knowledge, limited longitudinal data are available regarding the SI@V4 and η_p @V4 status throughout an entire season or a shorter period of time. Earlier observations concerning those variables aimed to analyze young swimmers and did not compare groups of different competitive level (Latt et al. 2009a, b). However, several cross-sectional studies have already suggested that Int swimmers present higher SI and η_p values than Nat ones (e.g. Toussaint 1990; Sánchez and Arellano 2002). Int swimmers are able to maintain higher SI values indicating an improved energetic capacity to delay the appearance of increased local muscular fatigue (Fernandes et al. 2006). Similar trend was also found in this study for the entire season.

Biomechanics

The more time spent in technical tasks had a positive effect on the stroke mechanics in both groups. However, different combinations were observed for the SF and SL relationships. Int swimmers presented an increase in the SL@V4 and a decrease in the SF@V4 across season with no significant meaning. At some point of their careers, elite swimmers obtain a maximal technical ability where it is difficult (but not impossible) to observe changes in stroke mechanics. Several papers reported that training imposed significant improvements in SL of top-level adult

swimmers, leading to an increase in swimming velocity (Wakayoshi et al. 1993; Termin and Pendergast 2000). As the $V4$ increased, there was less choice of combining $SF@V4$ and $SL@V4$. So, the single possibility was to increase in a higher range the $SL@V4$ reducing the $SF@V4$. The $SF@V4$ reduction is in accordance with the strategy adopted by elite swimmers that made them more efficient than lower level ones.

On the other hand, technical training induced an increase in both $SF@V4$ and $SL@V4$ for Nat swimmers. It was previously suggested that an increase in SF associated with a maintenance in SL should not be considered as ineffective for the 200-m freestyle performance (Huot-Marchand et al. 2005). So, the ability of Nat swimmers to use SF and SL relationship to progressively improve the energetic and biomechanical capacity is a major factor to enhance performance. Similar phenomenon was already observed in Division 1 male swimmers (Termin and Pendergast 2000).

When the inter-group comparison was carried out, the total improvement in $SL@V4$ was higher for the Int swimmers ($2.15 \pm 4.45\%$). Additionally, Int swimmers presented a higher $SL@V4$ and reduced $SF@V4$ than Nat ones at all time periods. Once again there is a lack of evidence about such topic in a longitudinal point of view, although it is consensual in cross-sectional design studies that high-level swimmers have an increased SL (Craig et al. 1985; Seifert et al. 2007). During the 100- and 400-m front crawl events faster swimmers tend to show a smaller decrease in SL than slower ones (Chollet et al. 1997; Laffite et al. 2004). Moreover, elite swimmers have the ability to maintain high SL values while increasing v through SF increases during incremental exercises (Barbosa et al. 2008). This fact may be related to an increased capacity to deliver power output presented by the more skilled swimmers (Toussaint and Beck 1992). The literature also suggests that anthropometric characteristics (Zamparo et al. 1996), higher skill level (Barbosa et al. 2008) or genetic background (Costa et al. 2009) are determinant in the swimmers competitive level, and may facilitate skill acquisition related to specific tasks.

Normative stability

This data analysis procedure is related to the possibility of a swimmer to demonstrate a “stable” profile in his characteristics when compared to other swimmers (if he remains on his specific track of competitive level across the season, or if he tends to jump to another). It reports the term “stability” based on inter-individual instead of an intra-individual point of view. Low K values were observed for $V4$ and $SL@V4$ throughout the competitive season suggesting that swimmers were able to change their

competitive level related to those variables. On the other hand, for the $SI@V4$ high K values were demonstrated. Despite the $SI@V4$ improvement observed for the Nat cohort, Int swimmers were able to increase their $SI@V4$ as well. So, for the Nat group, this slight change was not enough to change from a track of competitive level. Taking into account that $SI@V4$ values are near the statistical significance in TP_1 and TP_3 when comparing both groups, the $SI@V4$ can be used as an indicator of performance variation across the competitive season.

The tracking based on auto-correlation coefficients were high for most variables analyzed, except for the $V4$ ($0.33 \leq r \leq 0.82$) where a low–high stability was observed. This suggests that during a single season the margin of improvement for adult elite swimmers energetic and biomechanical profiles is too small. Indeed, their ability to reach a higher competitive level throughout a single season remains scarce. For two consecutive seasons high values of correlation coefficients were verified for anthropometric, body composition, biomechanical and energetic variables in young swimmers (Latt et al. 2009a, b). Nevertheless, when increasing the time frame analysis, the stability might decrease (Costa et al. 2010a). A couple of papers presented a moderate (Costa et al. 2010a) and low (Costa et al. 2010b) stability for elite swimmers competitive performance in a 5 and 7 years’ time frame, respectively. The low–high range in $V4$ stability can be related to several episodes that might play a major role such as: (1) an acute or a chronic injury (Wolf et al. 2009); (2) illness (Hellard et al. 2010); (3) overtraining (Pelayo et al. 1996) or; (4) preference to improve academic success instead of sports performance.

The small sample of subjects does not allow strong statements about the differences between Nat and Int swimmers. If one takes another small sample of subjects from some other Country then the present findings may (or may not) repeat. However, it was demonstrated that some practical parameters were stable enough to be used as diagnostic tools to observe changes in both biomechanical and energetic profiles along with enhancement of overall swimming performance. Although most of the times this kind of research are done with convenience samples, if possible, in future the use of larger number of subjects should be considered to avoid the power sample issue.

Conclusions

Despite slight changes, elite swimmers performance, energetic and biomechanical profiles remain unaltered throughout the competitive season. Int swimmers are able to maintain a higher energetic and biomechanical capacity than Nat ones at all time. Later in the season, those slight

changes in the 200-m freestyle performance are achieved due to an increase in anaerobic tasks and technical training. In addition, the SI@V4 can be used as an indicator of performance variation throughout the competitive season.

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Ethical standards The Institutional Review Board of the Polytechnic Institute of Bragança approved the study design. All subjects gave their informed consent prior to their inclusion in the study. The procedures were in accordance with the Declaration of Helsinki in respect to Human research.

Conflict of interest The authors declare that they have no conflict of interest.

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