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LONGITUDINAL INTERVENTIONS IN ELITE SWIMMING
Relationship between energetics, biomechanics and performance

Ph.D. in Sport Sciences

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This academic dissertation was submitted with the purpose of obtaining a doctoral degree in Sport Sciences according to the provisions of Portuguese Decree-Law 107/2008 of June 25th.

Dedicated to my parents…

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List of Abbreviations

(Aer) aerobic contribution

(AnS) anaerobic contribution

($[La^-]$) blood lactate concentrations

(La_{net}) difference between the lactate measured and the lactate at rest

(V_4) velocity at 4 mmol L^{-1} of blood lactate concentration

(La_{peak}) peak lactate concentration

(O_2Eq) oxygen equivalents

(VO_2) oxygen consumption

(VO_2max) maximal oxygen consumption

(VO_2net) difference between the oxygen uptake measured and the oxygen at rest

(vVO_2max) velocity of maximal oxygen consumption

(E_{tot}) total energy expenditure

(HR) heart rate

(C) energy cost

(v) velocity

(SI) stroke index

(SF) stroke frequency

(SL) stroke length

(η_p) propelling efficiency

($SI@V_4$) stroke index at velocity of 4 mmol L^{-1} of blood lactate concentration

($SF@V_4$) stroke frequency at velocity of 4 mmol L^{-1} of blood lactate concentration

($SL@V_4$) stroke length at velocity of 4 mmol L^{-1} of blood lactate concentration

($\eta_p@V_4$) propelling efficiency at velocity of 4 mmol L^{-1} of blood lactate concentration

(l) arms' length

(M) body mass

(k) Cohen kappa tracking index

(r) person correlation coefficient

(r_s) spearman correlation coefficient

(η^2) eta square

(HLM) hierarchic linear model

(CI) confidence interval

(SD) standard deviation

(n) number of subjects

(Int) international swimmers

(Nat) national swimmers

(TP) time period

Abstract

In the last couple of decades, research in competitive swimming has given special emphasis to energetic and biomechanical assessment as determinant domains to enhance performance. However, the majority of the studies conducted in this field had a cross-sectional approach, not considering the effect of annual training in the changing process. Thus, the aim of this thesis was to characterize the adaptations in elite swimmers performance, energetic and biomechanical profiles, and understand the relationship established between these domains in a longitudinal perspective. With that purpose, this work is divided in to six independent studies. The first study was based in a systematic review that consolidated the practical findings from the studies that previously published about this thematic. The purpose of the following two papers was to understand the performance progression from childhood to adulthood and during an Olympic Cycle, by conducting a retrospective analysis of the elite swimmers annual best performances. The remaining three experimental studies aimed to verify the effect of the annual training on the energetic and biomechanical profiles and determine the factors that most contributed for the performance enhancement. The main conclusions drawn were: (i) the few existing longitudinal studies in swimming science present low quality scores; (ii) sixteen years-old is the age at which the ability to predict adult performance increases markedly; (iii) high stabilization in freestyle performances was evident at the third season of an Olympic cycle; (iv) elite swimmers only demonstrated slight changes in their performance, energetic and biomechanical profiles at least throughout two seasons; (v) the magnitude of change was dependent on the duration of the intervention, type of training done and competitive level; (vi) each swimmer demonstrated a different changing profile in response to the training load applied and; (vii) the aerobic capacity and the stroke kinematic factors, namely in the stroke length and stroke frequency, were the factors that most contributed for the 200 m freestyle performance enhancement. As main conclusion it can be stated that elite swimmers present an individual way in demonstrating slight adaptations in their performance, energetic and biomechanical profiles.

Keywords: *swimming, stability, change, elite swimmers, training*

Resumo

Nas últimas décadas a investigação em natação centrou-se fortemente nos fatores bioenergéticos e biomecânicos tomando-os como principais preditores do rendimento. No entanto, a maioria dos estudos sobre a temática apresenta um caráter transversal, não tendo em consideração o fenómeno da mudança como um processo natural devido ao treino. Foi objetivo da presente tese caracterizar as mudanças no perfil bioenergético, biomecânico e na performance de nadadores de elite, compreendendo as relações estabelecidas entre estes dominios numa perspetiva longitudinal. Esta dissertação divide-se em seis estudos indepedentes que foram realizados com esse propósito. O primeiro estudo centrou-se num processo de revisão sitemática com o intuito de consolidar as evidências práticas dos estudos baseados na temática já publicados. O dois estudos seguintes recorreram a uma análise retrospectiva da performance, de modo a intepretar a sua progressão desde a idade jovem até à idade adulta e ao longo de um ciclo Olímpico. Os três estudos finais de caráter experimental objetivaram determinar o efeito do treino anual no perfil bioenergético e biomecânico, tentando determinar os fatores que mais e melhor contribuiram para a melhoria da performance. As conclusões que advêm do presente trabalho são as seguintes: (i) os poucos estudos longitudinais existentes no domínio da natação apresentam reduzidos índices de qualidade; (ii) os tempos na prova de livres demonstraram uma tendência para começar a estabilizar a partir dos 16 anos de idade; (iii) a performance na terceira época do ciclo Olímpico é determinante dada a elevada estabilidade que é posteriormente demonstrada nos tempos de prova até ao ano Olimpico; (iv) nadadores de elite apenas foram capazes de evidenciar mudanças ténues no seu perfil bioenergético, biomecânico e na performance pelo menos durante dois anos; (v) a magnitude dessa ligeira mudança foi depedennte do tempo de duração do estudo, do tipo de treino efetuado e do nível competitivo do nadador; (vi) cada nadador demonstrou um perfil de adaptação individualizado em resposta ao treino e; (vii) o aumento da capacidade aeróbia e o aperfeiçoamento dos indicadores cinemáticos da braçada, nomedamente na distância de ciclo e frequência gestual, foram os fatores que mais contribuiram para uma melhoria no tempo de 200 m crol em condições de competição. Deste modo podemos concluir que existe uma forma individualizada na maneira como nadadores de elite demonstram pequenas melhorias no perfil bioenergético, biomecânico e na peformance.

Palavras-chave: *natação, estabilidade, mudança, nadadores de elite,*

General Introduction

Competitive swimming it is considered one of the most challenging sports within the closed and cyclical activities. The main aim for swimming coaches and researchers relies on the identification of the factors that might predict, with higher validity and accuracy the performance. Recently, scientific highlights have been reported between performance and kineanthropometrical characteristics (Saavedra et al., 2002), psychological factors (Robazza et al., 2008), physiological/energetics (Fernandes, 2006a), biomechanics/technical ability (Barbosa et al., 2008), hydrodynamics (Kjendlie et al., 2008; Silva et al., 2008), genetic background (Costa et al., 2009) or nutritional issues (Zajac et al., 2009). From those, energetics and biomechanics were the most attractive areas of research (Vilas-Boas 2010; Barbosa et al., 2010a).

Cross-sectional studies suggested a hierarchical contribution from energetics and biomechanics to performance. It seems that performance it is strongly linked to energetic variables, since these in turn, are dependent on the biomechanical behavior and the motor strategies adopted (Barbosa et al., 2010b). However, such cross sectional interventions were less comprehensive and informative about the cause-and-effect relationships in a long-term perspective. Training sets are developed in order to improve both physiological and technical capacity within and between seasons. So, the ability to monitoring changes in energetic and biomechanical terms provides fundamental information for coaches on the response of their swimmers to training periodization. Longitudinal studies are required to do this. The longitudinal assessment implies the notions of repeated measures. Swimmers are submitted to the same experimental procedures and evaluated at a certain number of occasions that are equally spaced in time. Extending those measurements beyond one single evaluation moment a sequence of events can easily be established (Van der Kamp and Bijleveld, 1998).

There are few longitudinal studies in elite swimmers, and the ones that have been conducted aimed to: (i) analyze the performance progression within and between seasons (Stewart and Hopkins, 2000; Mujika et al., 2002; Pyne et al., 2004; Trewin et al., 2004); (ii) determine the swimmers energetic and/or biomechanical adaptations to annual training (Sharp et al., 1984; Ryan et al., 1990; Costill et al., 1991; Termin and Pendergast, 2000; Pyne et al., 2001; Anderson et al., 2006) and; (iii) observe the effect of different types of training on factors affecting performance, (Houston, 1981; Faude et al., 2008). Based on these studies, it is known that the performance of elite swimmers changes within the season (Pyne et al., 2004). Indeed, the last

stage of preparation before important competitions has trivial importance in peaking for optimal performance (Mujika et al., 2002). However, there are few scientific evidences about the performance progression and stability within larger time periods such as an Olympic cycle or during the full (or all most) swimmer's career. From that point of view, it is possible to determine specific chronological points where the performance prediction increases based on the progression of earlier performances. Annual energetic and biomechanical adaptations seem to be consistent as well (Sharp et al., 1984; Ryan et al., 1990; Costill et al., 1991; Termin and Pendergast, 2000; Pyne et al., 2001). Nevertheless, most of the earlier studies fail to demonstrate the inter-individual response to training. To the best of our knowledge only one single study has examined individual responses with such purpose. Anderson et al. (2006) found a large variability between gender and competitive level in energetic and biomechanical adaptations. This trend for individual assessment is growing and making much more sense in closed and cyclical sports, such as swimming. The identification of the swimmer's most comfortable individual combination on energetic and biomechanical aspects facilitates the adequate prescription for further improvements. Thus, new highlights are required, in order to better understand the inter-individual changes within and between seasons of training.

The clarification of the factors with a positive effect on swimming performance in longitudinal perspective is also a major component for training diagnosis. Coaches can easily manipulate those aspects to ensure a performance enhancement. From the few attempts conducted in that approach, only evidences in young swimmers were published. Longitudinal data revealed that the biomechanical factors, namely the stroke index, characterized best the 400 m freestyle performance over two consecutive seasons (Latt et al., 2009a; Latt et al., 2009b). Authors also stated that boys depended mainly from anthropometrics (arm spam) and girls from energetics, when following the biomechanical ones. This kind of approach was never attempted taking elite swimmers as subjects. In addition, the identification of the performance predictors using hierarchical linear model was never attempted in swimming "science". However, in some other sports and scientific fields, such as for instance, distance running (Bragada et al., 2010) and physical activity (Lopes et al., 2011) some evidences exists on that. This method creates a hierarchical structure like a "tree", being able to identify, in a more accurate way the energetic and biomechanical variables as performance changing predictors, and to determine the relative contribution of each one during such period.

Based on cross sectional evidences it is know that swimmers from different competitive levels present different energetic and biomechanical profiles. High-level swimmers are more

economical (e.g., energy expenditure at a given velocity) and efficient than lower-level ones (Toussaint, 1990; Fernandes et al. 2006b). It seems that international level swimmers are able to maintain higher stroke index values, suggesting an improved energetic capacity to delay the appearance of increased local muscular fatigue (Fernandes et al., 2006b). International level swimmers also present higher stroke index values when compared to the national counterparts (Sánches & Arellano, 2002). Moreover, the stroke length (Seifert et al. 2007) and the propelling efficiency (Toussaint 1990) are higher in elite swimmers, while the active drag (Pendergast et al. 2006) is lower, at a given speed or swim pace, when compared to less skilled ones. Nevertheless still remains some doubts regarding the differences in the response of international and national level swimmers to annual training.

Therefore, the main purpose of this thesis was to conduct an energetic, biomechanical and performance evaluation in elite swimmers, aiming to understand the interplay among these domains in a longitudinal perspective.

The thesis has the following main chapters:

- Chapter 1 presents a systematic review based on the earlier longitudinal studies regarding the performance, energetic and biomechanical status of elite swimmers.

- Chapter 2 demonstrates the elite swimmers freestyle performance progression from childhood to adulthood, trying to predict the swimmers competitive level at adult age based on a retrospective analysis.

- Chapter 3 is based on the analysis of the World-Ranked swimmers performance during an Olympic cycle, considering the stability in race times taking into account the Olympics season.

- Chapter 4 relies on the monitorization of elite swimmers performance, energetic and biomechanical profiles over two consecutive seasons, trying to discriminate the global and individual response to training, and identify the best predictors of performance.

- Chapter 5 aims to add new evidences on the annual changes in performance and other energetic variables assessed regularly.

- Chapter 6 demonstrates the differences between international and national level swimmers in terms of performance, energetic and biomechanical annual adaptations.

Then, a general discussion of the results obtained in the six independent studies is performed and the main conclusions of the thesis are presented.

Chapter 1

Longitudinal interventions in elite swimming: a systematic review based on energetics, biomechanics and performance

Abstract

Longitudinal information requires the notion of repeated measurements throughout time. Such data is important since allows the determination of the effectiveness of an intervention program. Research in competitive swimming has given special emphasis to energetics and biomechanics as determinant domains to improve performance. The purpose of this systematic review was to summarize longitudinal evidences on the energetic, biomechanical and performance status of elite swimmers. A computerized search was made in six databases, conference proceedings and department files. The 28 studies that satisfied the inclusion criteria were selected for analysis. Studies' qualitative evaluation was made by two independent reviewers using the Quality Index. These studies were then gathered into three main categories according to their reported data: energetics (n=18), biomechanics (n=9) and/or performance (n=8). The conclusions were: (i) elite swimmers are able to demonstrate from slight to substantial changes in their performance, energetic and biomechanical profiles within and between seasons; (ii) the magnitude of change is dependent from the characteristics of the training programs, the duration of the intervention and subject's gender, and (iii) future research should emphasize the use of more complex procedures to improve the quality of the interventions.

Keywords: *elite swimmers, seasonal variation, kinematics, training*

Introduction

Research in competitive swimming has given special emphasis to energetic and biomechanical assessments. The performance is strongly linked to energetic variables, as those are dependent from biomechanical profile and motor strategies adopted by the swimmers (Barbosa et al., 2010). At the moment, most of the recent reviews conducted about this topic (Toussaint and Beck, 1992; Toussaint and Hollander, 1994; Barbosa et al., 2010) report evidences exclusively based on cross-sectional studies. The defining feature of a cross-sectional study is that it can compare different population groups (i.e. cohort groups) and different variables at a single time moment. Such interventions are less comprehensive and informative about the cause-and-effect relationships in a long-term perspective. On the other hand, the longitudinal assessment implies the notions of repeated measures, i.e., the observations are collected at a certain number of occasions. Extending its measurements beyond a single time moment a sequence of events can easily be established (Van der Kamp and Bijleveld, 1998). Thus, it seems that longitudinal interventions can bring more benefits than cross-sectional studies.

There are few longitudinal studies on competitive swimming when compared to other sports (e.g. running). Most of those papers were published in peer-reviewed and indexed journals showing the strong effect of their findings. Indeed, the consolidation of those evidences retrieving some major guidelines is an important tool for coaches' daily intervention. However, to the best of our knowledge it does not seem to exit any review about longitudinal interventions on competitive swimming.

Longitudinal data plays a major contribution in helping coaches defining realistic goals and training procedures between competitions and/or seasons (Pyne et al., 2004). This kind of information on energetic and biomechanical terms is a useful tool to determine the effectiveness of the previous load, helping enhancing performance (Termin and Pendergast, 2000). Moreover, the longitudinal performance judgment by itself can be a useful adjunct for the prediction phenomena. Chronological points can be used to predict performance levels (Costa et al., 2010b), or even to determine the probability of winning a medal in a specific event (Pyne et al., 2004; Trewin et al., 2004).

The purpose of this systematic review was to summarize evidence about the changes and relationships between energetics, biomechanics and/or performance throughout longitudinal interventions in elite swimmers. This type of work was thought to breach more clearly the gap

between theory and practice by assisting the coaches in their training prescription and to highlight areas for further research.

Methods

All the methodological procedures were conducted considering the standards for systematic reviews suggested by the Institute of Medicine of the National Academy (Washington, US). Systematic researchers in the thematic conducted the process to fulfill the suggestions and guidelines given by McGowan and Sampson (2005), such as: (i) the need of transparency (readers should be able to verify that the review is not open to bias) and; (ii) reproducibility (readers and other researchers should be able to replicate the methods and arrive at the same results).

Search Strategy

A search of the literature (Figure 1) was conducted from January 1st of 1970 until December 31th of 2010 using electronic literature databases (PubMed, ISI Web of Knowledge, Index Medicus, MEDLINE, Scopus, SPORTDiscus) and use of departmental files, including conference proceedings. Several keywords (longitudinal, kinematics, biomechanical, energetics, physiological, performance, swimming, elite swimmers, training season, monitoring, variation, relationships, tracking and changes) were used in the search strategy, with multiple combinations and with no language restrictions. Two independent searches produced two different lists of publications that were then consolidated into a single list. Results were initially screened by title to exclude any obviously irrelevant articles. Potential hits that meet the inclusion criteria were after hand searched. When necessary, attempts were made to contact the authors to obtain the missing paper.

Inclusion and Exclusion Procedures

Included studies focused on longitudinal interventions on energetics, biomechanics and performance of elite swimmers. "Elite swimmer" is defined as an athlete at adult age that is near or has already reached his/her top career demonstrating regular presence on the most important National and/or in International Competitions. Excluded were: (i) studies not having at least two equal field interventions with the same subjects; (ii) studies based on other swimming topics; (iii) studies using other chronological ages (e.g. children, age-group or

masters) instead of adult elite swimmers and; (iv) studies focused on a single individual or in a few number of swimmers (e.g. N < 5). In respect to the research question, relevant studies were categorized in three main groups: (i) energetics, where interventions generally aimed to observe the evolution of energetic confounders throughout time, or to detect possible changes according to training prescription and its influence on performance; (ii) biomechanics, where interventions aimed to understand the contribution of biomechanical changes into performance enhancement, and (iii) performance, where authors aimed to analyse the performance behaviour to predict future results. The information extracted from the included studies was based on: (i) design and setting; (ii) sample characteristics; (iii) aim of the intervention and; (iv) major findings.
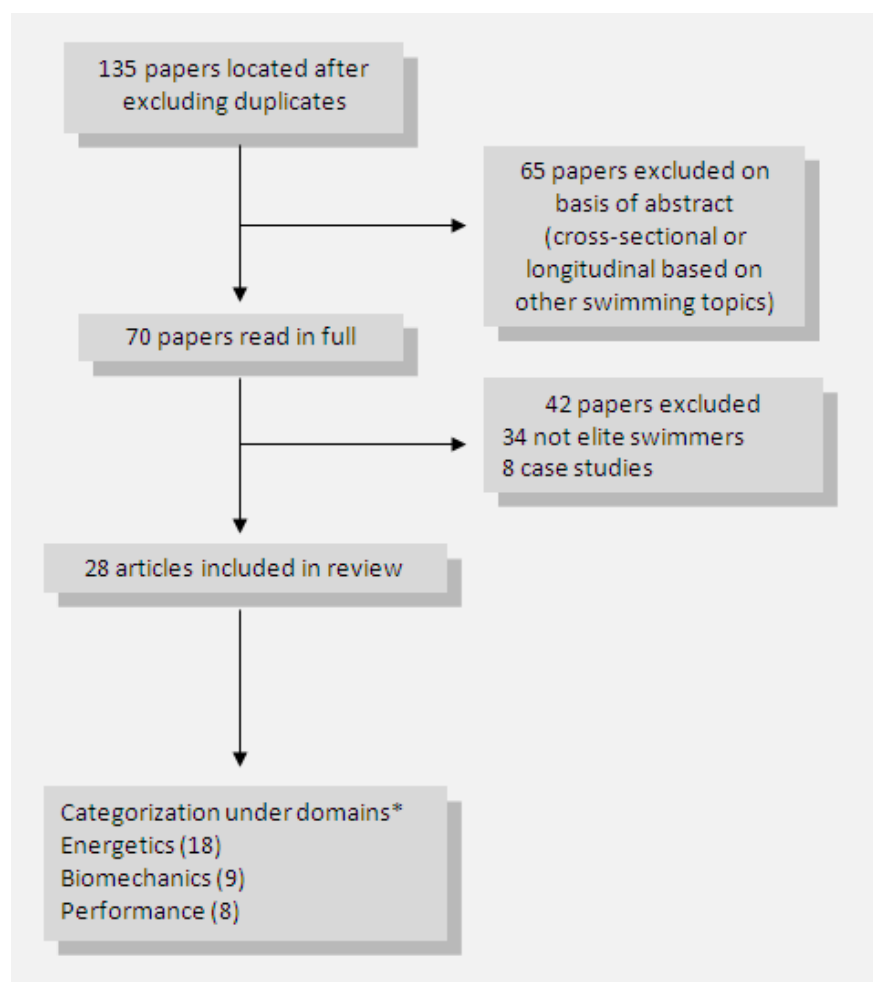
Figure 1. Search Strategy. * Seven studies included in both energetic and biomechanical domains.

Quality Assessment

All relevant studies underwent a formal evaluation by two independent reviewers. Since there is no validated quality assessment tool suitable for this kind of field interventions (i.e., sports performance), the Quality Index was used (Downs and Black, 1998). This index presents a large range of scoring profiles: reporting, internal validity, external validity and power. In each profile all items received rating scores, where the maximal score possible to obtain from the index was 32 points. When necessary or appropriate, disagreements between reviewers were solved by discussion and consensus. The degree of agreement in scoring procedure was obtained based on the Kappa index (K) and thresholds interpreted according to Landis & Koch's suggestion (1977), where there is: (i) no agreement if $K \leq 0$; (ii) poor agreement if $0 < K \leq 0.19$; (iii) fair agreement if $0.20 < K \leq 0.39$; (iv) moderate agreement if $0.40 < K \leq 0.59$; (v) substantial agreement if $0.60 < K \leq 0.79$ and; (vi) almost perfect agreement if $0.80 < K \leq 1.00$.

Results

Our search identified 135 potential relevant papers of which 107 did not meet the inclusion criteria. As shown in Figure 1 the reasons for exclusion were being cross-sectional (32 studies), longitudinal focused on other topics (33 studies), participants from other chronological ages (34 studies) and case studies (8 studies). A total of 28 studies were considered for further analysis. From these, the earliest one was published in 1981 (Houston et al., 1981) and the most recent in September of 2010 (Costa et al., 2010a). Studies were assigning for each category according to their reported data (Table 1): (i) energetics (18 studies); (ii) biomechanics (9 studies), and (iii) performance (8 studies). Because seven studies demonstrated evidences in different domains, they were included in both energetic and biomechanical categories.

The Quality Index scores ranged from 9 to 19 points individually, representing a mean of 11.68 points. Studies scored similar in their reporting style. All studies performed poorly in their external validity, internal validity and power. Only one study used random sampling to include subjects that would be representative for the entire population. In nine studies subjects could not be aware of which interventions they received. At least three studies indicated the power magnitude to detect an important practical effect. The reliability between both reviewers showed an almost perfect agreement (0.87) in the scoring procedure.

Group 1: studies of longitudinal interventions on energetics

Eighteen studies in table 1 have monitored changes in elite swimmers energetic profile. The overall quality scores ranged between 9 and 19 points. Interventions generally aimed to assess blood lactate concentrations ($[La^-]$) at submaximal swimming speeds (Sharp et al., 1984; Costill et al., 1991; Wakayoshi et al., 1993; Pyne et al., 2001; Thompson et al., 2003; Anderson et al., 2006; Roels et al., 2006; Anderson et al., 2008; Santhiago et al., 2009; Robertson et al., 2010), maximal $[La^-]$ (Pelayo et al., 1996; Termin and Pendergast, 2000; Bonifazi et al., 2000; Anderson et al., 2006; Faude et al., 2008), maximal oxygen consumption ($VO_2máx$) (Houston et al., 1981; Termin and Pendergast, 2000; Roels et al., 2006; Rodriguez et al., 2007), heart rate (HR) (Houston et al., 1981; Sharp et al., 1984; Anderson et al., 2006; Atlaoui et al., 2007; Faude et al., 2008) and energy cost (C) (Termin and Pendergast, 2000; Roels et al., 2006; Rodriguez et al., 2007). The reported duration of field interventions ranged from five weeks (Faude et al., 2008) to six seasons (Anderson et al., 2006)

Group 2: studies of longitudinal interventions on biomechanics

Table 2 included nine relevant studies that tracked changes in elite swimmers biomechanical profile. The quality scores ranged from a minimum of 10 points to a maximum of 12 points. Interventions generally aimed to assess stroke frequency (SF) (Johns et al., 1992; Wakayoshi et al., 1993; Termin and Pendergast, 2000; Thompson and Cooper, 2003; Huot-Marchand et al., 2005; Anderson et al., 2006; Faude et al., 2008 18, 20) and stroke length (SL) (Costill et al., 1991; Johns et al., 1992; Wakayoshi et al., 1993; Termin and Pendergast, 2000; Anderson et al., 2006; Huot-Marchand et al., 2005;). The duration of the interventions ranged from 14 days (Johns et al., 1992) to six seasons (Anderson et al., 2006).

Group 3: studies of longitudinal interventions on performance

Table 3 summarizes the eight studies that analyzed the performance variation within or between seasons. Quality scores ranged between 9 and 13 points individually. Studies used race times (Stewart and Hopkins 2000; Mujika et al., 2002; Pyne et al., 2004; Issurin et al., 2008; Costa et al., 2010a; 2010b;) or ranking positioning (Trewin et al., 2004; Sokolovas, 2006) for that purpose. The time of the intervention lasted between 20 days (Stewart and Hopkins 2000) and 9 seasons (Sokolovas 2006).

Table 1. Summary of the studies concerning longitudinal interventions on energetics.

Authors (reference)	Quality Score	Design and setting	Sample characteristics	Intervention	Findings
Houston et al. 1981	10	2 testing occasions in 6.5 weeks	10 University swimmers	Effects of two types of training on VO$_2$máx and HR	VO$_2$máx remained unaltered. HR was significantly lower
Sharp et al. 1984	9	3 testing occasions during 6 months	12 University swimmers	Detect changes in [La⁻] and HR	[La⁻] at submaximal velocity improved . HR remained unaltered
Ryan et al. 1990	10	6 testing occasions during 6 months	14 University swimmers	Effects of training volume on [La⁻]	[La⁻] at submaximal velocity improved
Costill et al. 1991	11	7 testing occasions during 25 weeks	24 Collegiate swimmers	Effects of an increased training volume on [La⁻]	[La⁻] at submaximal velocity improved
Wakayoshi et al. 1993	11	2 testing occasions spaced by 6 months	8 College swimmers	Effects of aerobic training on [La⁻]	[La⁻] at submáximal improved
Pelayo et al. 1996	10	6 testing occasions during 23 weeks	6 International and National swimmers	Effects of training on the [La⁻] related with recovery	Maximal [La⁻] related with recovery increased with overtraining
Bonifazi et al. 2000	11	2 testing occasions spaced by 18 weeks	8 International swimmers	Relationships between post-exercise [La⁻] and performance	Increases in maximal [La⁻] were positively correlated with performance
Termin & Pendergast 2000	11	12 testing occasions during 4 seasons	22 US Division 1 swimmers	Effects of high velocity training on maximal [La⁻], VO$_2$máx and C	Maximal [La⁻], VO$_2$máx and C improved
Pyne et al. 2001	12	4 testing occasions during 8 months	12 World-Ranked swimmers	Association between [La⁻] and performance	[La⁻] at submaximal velocity improved but was not associated with performance
Thompson & Cooper 2003	12	2 testing occasions during 12 months	11 Nationally-Ranked swimmers	Association between [La⁻] at submaximal speeds and performance	[La⁻] at submaximal velocities were significant related with performance
Anderson et al. 2006	12	396 tests during 6 seasons	40 International and National swimmers	Characterize seasonal changes in [La⁻] at submaximal speeds and HR	[La⁻] at submaximal velocity and maximal [La⁻] improved. HR presented trivial changes.
Roels et al. 2006	12	4 testing occasions during 10 weeks	8 International swimmers	Effects of altitude training on VO$_2$máx and C	VO$_2$máx and C remained unaltered
Atlaoui et al. 2007	10	3 testing occasions during 7 weeks	13 International and National swimmers	Relationships between HR and performance	HR remained unaltered and was not related with performance
Rodriguez et al. 2007	19	4 testing occasions during 11 weeks	13 Collegiate swimmers	Effects of altitude training on VO$_2$máx and C	VO$_2$máx and C remained unaltered
Anderson et al. 2008	11	10 tests by swimmer during 5 seasons	40 International and National swimmers	Seasonal changes in [La⁻] at submaximal speeds	[La⁻] at submaximal velocity improved
Faude et al. 2008	12	4 testing occasions during 5 weeks	10 National swimmers	Effects of two types of training on [La⁻] and HR	[La⁻] at submaximal velocity and maximal [La⁻] improved. HR remained unaltered
Santhiago et al. 2009	11	4 testing occasions during 14 weeks	23 Olympic and International swimmers	Submaximal [La⁻] responses in different training phases	[La⁻] at submaximal velocity remained unaltered
Robertson et al. 2010	13	4 testing occasions during 21 weeks	18 International and National swimmers	Effects of altitude training on [La⁻] at submaximal velocities	[La⁻] at submaximal velocities presented modest changes

Table 2. Summary of the studies concerning longitudinal interventions on biomechanics.

Authors (reference)	Quality Score	Design and setting	Sample characteristics	Intervention	Findings
Costill et al. 1991	11	7 testing occasions during 25 weeks	24 Collegiate swimmers	Effects of an increased training volume on SL	SL significantly improved
Johns et al. 1992	10	3 testing occasions during 14 days	12 Intercollegiate swimmers	Effects of taper on SL and SF	SL and SF remained unaltered
Wakayoshi et al. 1993	11	2 testing occasions spaced by 6 months	8 College swimmers	Effects of aerobic training on SL and SF	SL increased significantly. SF remained unaltered
Termin & Pendergast 2000	11	12 testing occasions during 4 seasons	22 US Division I swimmers	Effects of high intensity training on SL and maximal SF	SL and maximal SF increased
Thompson & Cooper 2003	12	2 testing occasions during 12 months	11 Nationally-Ranked swimmers	Association between SF and performance	Increases in SF were significantly related with decreases in performance
Huot-Marchand et al. 2005	11	2 testing occasions spaced by 2 years	17 International and National swimmers	Association between SL, SF and performance	SF increased and was significantly related with performance improvements. SL remained unaltered
Anderson et al. 2006	12	396 tests during 6 seasons	40 International and National swimmers	Seasonal changes in SL and SF	SL decreased and SF increased in males. SL increased and SF decreased in females
Anderson et al. 2008	11	10 tests by swimmer during 5 seasons	40 International and National swimmers	Variation of SF at submaximal velocity	Submaximal SF improved
Faude et al. 2008	12	4 testing occasions during 5 weeks	10 National swimmers	Effects of a taper on SF	SF remained unaltered.

Table 3. Summary of the studies concerning longitudinal interventions on performance.

Authors (reference)	Quality Score	Design and setting	Sample characteristics	Intervention	Findings
Stewart & Hopkins 2000	13	Performances collected between 20 days	221 National level swimmers	Performance consistency within and between competitions	Performance variation was 1.4 % in the same event, 1.7 % between distances for a given stroke, and 2.7% between strokes for a given distance.
Mujika et al. 2002	13	Performances collected in two major competitions	99 Olympic swimmers	Performance progression in the final stage leading to the 2000 Olympic Games	Performance improved 2.57% and 1.78% for males and females respectively
Pyne et al. 2004	12	Performances collected during 12 months	676 performances of 51 Olympic swimmers	Performance progression leading to the 2000 Olympic Games	Performance improved 1% within a competition and 1% within a year. An additional 0.4% enhancement increased the chance to win a medal.
Trewin et al. 2004	13	Performances collected during 9 months	407 Olympic swimmers	Relate the annual ranking positioning with the 2000 Olympic Games performance	Most of Olympic medalists had a top-10 world ranking. An additional 0.6% enhancement in performance will increase the chance to win a medal.
Sokolovas 2006	9	Ranking positioning during 9 seasons	USA top-100 performances	Presence in US top-100 ranking positioning from 10 to 18 years	Low stability was presented.
Issurin et al. 2008	13	Performances collected in 2 major competitions	301 Olympic swimmers	Performance progression in the final stage leading to the 2004 Olympic Games	Performance improved ~0.6 % between trials and Olympics.
Costa et al. 2010a	13	Performances collected during 5 seasons	2385 performances of 477 World-Ranked swimmers	Performance progression during the 2004-2008 Olympic cycle	Performance improved between seasons ~0.6-1 %, reaching high stability (r > 0.60) in the third season of the Olympic cycle.
Costa et al. 2010 b	13	Performances collected during 7 seasons	905 performances of 35 Nationally-Ranked swimmers	Stability of breaststroke performance from 12 to 18 years	Low stability (r < 0.30) was presented. The prediction of adult competitive level increased at the age of 16.

Discussion

The main focus of this investigation was to summarize evidence about longitudinal interventions on elite swimmers. In this research it was verified that elite swimmers presented from slight to substantial changes in performance, energetics and biomechanical profiles through intervention period. The magnitude of change is dependent from the characteristics of the training programs, duration of the intervention and the subject's gender.

There is a trend for the majority of the papers included in this study to present low quality scores, when compared to similar approaches in other scientific domains (e.g., health sciences and social sciences). On overall, swimming teams have only a small number of caliber swimmers to be assessed. In order to overcome this issue, most researchers in this field adopt convenience samples. The main disadvantage for this kind of samples is the inability to extrapolate the result for all population. In addition, the existing tools used for quality assessment were built based on more accurate scientific areas. On a regular basis, they are focused on complex procedures such as randomization, blindness, the use of control group and/or practical effects. The absence of such procedures affects the quality score given to swimming interventions. It should be expected a low/moderate quality score for this kind of studies. In near future, swimming researchers should consider those aspects aiming to improve the quality of further interventions.

Energetics

One important practical consideration for coaches is the importance of monitoring energetic adaptations within and between seasons. The studies included in this review regarding the aerobic capacity present similar trends. Aerobic capacity determined by the $[La^-]$ at submaximal swimming speeds improves over the season. Two studies (Pyne et al., 2001; Anderson et al., 2006) indicated a small but meaningful annual improvement in the 4 mmol of lactate speed by ~2.2% for females and ~1.5% for males. Four studies (Sharp et al., 1984; Ryan et al., 1990; Costill et al., 1991; Wakayoshi et al., 1993) reported that an increase in training volume is sufficient to induce such adaptations. From those, two studies (Sharp et al., 1984; Ryan et al., 1990) observed that the highest degree of change is achieved in the earliest months of the season. At that season's stage the muscle is more sensitive and able to improve the ability to produce energy aerobically (Pyne et al., 2001). In this sense, coaches should develop aerobic capacity of their swimmers at the beginning of the season, before more specific and high intensity training. From this moment forward, aerobic capacity remains

almost stable until the end of the season. Conversely, additional volume increases will not promote significant changes in the aerobic capacity. At least one study (Ryan et al., 1990) reported that increases in training yardage above 54.000 yds/wk during the remainder of the training season did not alter the aerobic capacity in elite female swimmers. At this point of the season elite swimmers have reached their personal aerobic peak. To improve or maintain the performance at higher levels coaches should focus on different training intensities aiming to develop other energy sources.

The maximal $[La^-]$ can be used as an anaerobic capacity estimation (Avlonitou, 1996). Included studies about this topic observed that maximal $[La^-]$ increases throughout the season as well (Termin and Pendergast, 2000; Bonifazi et al., 2000; Anderson et al., 2006, Faude et al., 2008). One of those studies (Faude et al., 2008) reported significant improvement from mid phases until the end of the season. An improved anaerobic capacity allows the swimmer reaching higher velocities at an increased oxygen debt and reduced muscle fatigue. Studies included in this review observed substantial improvements (from ~12% to ~27%) in the maximal $[La^-]$ of male swimmers within one full season (Termin and Pendergast, 2000; Anderson et al., 2006, Faude et al., 2008). In contrast, only trivial changes (~2%) were evident for their female counterparts (Anderson et al., 2006). Indeed, one of those studies (Anderson et al., 2006,) determined a large degree (~28%) of within-athlete variation in respect to maximal $[La^-]$ improvements. Differences in the magnitude of change can be accounted to the type of the training done, as well as to genders specific adaptations within the season.

At least three studies (Ryan et al., 1990; Pyne et al., 2001; Anderson et al., 2006) reported that improvements within the season in aerobic and anaerobic capacities are cyclical in nature. It is expected that some capacities will be lost (i.e. detraining phenomena) in off-season. One of those studies (Anderson et al., 2006) determined a loss of ~0.9% for males and ~1.2% for females in their aerobic fitness during the transition from one season to the following one. Previous observations have already reported that elite swimmers should keep their conditioning, or at least minimize the detraining effects, during the transition period. This concern showed to be beneficial to training adaptation in the beginning of the following season (Mujika et al., 1995). For this reason, coaches should advise their swimmers to remain active in off-season. It is important to perform other physical activities rather than swimming to maintain their fitness at higher levels. Added to that, swimmers should also undertake some swimming sessions, mainly to maintain the water sensitivity and their basic technique efficiency.

There seems to exist few studies and little consensus regarding the VO_2max status throughout the season. From the two studies found, only one study (Termin and Pendergast, 2000) presented an increase in the VO_2max within the season. Conversely, the other one (Houston et al., 1981) observed that VO_2max remained slightly unaltered with training. Two hypothetical explanations for the discrepancy between results are: (i) the training intensity selected in those studies and; (ii) the duration of the intervention program. The 6.5 weeks of moderate and high intensity training were not sufficient to promote substantial adaptations in the VO_2max (Houston et al., 1981). Any attempt to induce substantial adaptations may require a new specific type of training or a longer period of time to be expressed. One full season of high intensity training with lower volumes was able to increase the VO_2max in 20 % (Termin and Pendergast, 2000). Although the capacity to transport and utilize oxygen increases as the result of high intensity training, this increase tends to decrease through consecutive seasons. Termin and Pendergast (2000) observed increases in VO_2max of 20%, 9%, 8% and 5% after each of four consecutive seasons, respectively. Because at some point of their careers elite swimmers reach their predetermined genetic limit, from a statistical point of view becomes very difficult to observe significant differences between seasons.

Regarding HR variability, five studies (Houston et al., 1981; Sharp et al., 1984; Anderson et al., 2006; Atlaoui et al., 2007; Faude et al., 2008) were included in the present review. Four studies (Houston et al., 1981; Sharp et al., 1984; Anderson et al., 2006; Faude et al., 2008) were focused on maximal HR values, while one study (Atlaoui et al., 2007) reported adaptations in HR at rest. Evidence suggests that elite swimmers present trivial changes in HR variability over the season. There are also gender specific differences in HR adaptations between seasons. While the maximal HR for the males was relatively stable between seasons, females had a 1.1% decrease each year (Anderson et al., 2006). It is known that meaningful changes in stroke volume do not appear in trained athletes (Kubukeli et al., 2002). Indeed, the HR variability within the season is not correlated with performance (Atlaoui et al., 2007). However, one study (Faude et al., 2008) reported a significant decrease in maximal HR for this kind of subjects. In such paper, swimmers were submitted to a 6.5 weeks of high intensity training program. It could be hypothesized that the training load may lead to central adaptations, promoting a heart rate decrease. Added to that, this data can also suggest an overtraining issue.

In an attempt to explore further adaptations beyond conventional training, some coaches dedicate some part of their periodization programs to train in altitude. Three studies (Roels et al., 2006; Rodriguez et al., 2007; Robertson et al., 2010) assessing energetic adaptations

induced by altitude training were found. The interventions consisted of short duration periods living in high (> 2500 m) and training at low (~ 600 to 1200 m), or moderate (~ 1350 to 2500 m) altitudes. While the VO_2max and C remained unaltered after interventions (Roels et al., 2006; Rodriguez et al., 2007), the $[La^-]$ related to submaximal swimming speeds presented modest changes (Robertson et al., 2010). The absences of substantial gains were already reported in other closed and cyclic sports (e.g. running, cycling). There still remains a doubt of the usefulness of such programs inducing positive effects in elite athlete's performance.

Therefore, in respect to further longitudinal energetic programs it can be useful to highlight evidences regarding the within and between season variation of other energetical variables. In addition, new highlights are required in order to understand the effects of reduced and prolonged detraining period and also to more deeply explore the effects of altitude training in this kind of subjects.

Biomechanics

The biomechanical adaptations within and between seasons are important for coaches to determine the effectiveness of their technical sets to enhance stroke kinematics. The SL and SF have been described as useful variables to monitor swimming technique (Craig and Pendergast, 1979). While the SL is the distance that the body travels during a full stroke cycle, the SF represents the number of full strokes performed within a given period of time.

Coaches should know the existence of gender specific adaptations in these biomechanical variables within and between seasons. Two included studies (Termin and Pendergast, 2000; Anderson et al., 2006) showed that males tend to increase SF and decrease SL in 1% to 2% each season. In contrast, female swimmers typically have a non-meaningful decrease in SF and an increase of 0.9% in SL (Anderson et al., 2006). Individual adaptations to similar training programs may explain the discrepancies between genders. Males tend to became stronger by increasing lean mass throughout the season (Anderson et al., 2006). Their higher availability for dry-land training than females may contribute to higher benefits for performance. The positive transfer between dry-land strength gains and swimming propulsive force only are evident with specific training (Tanaka et al., 1993). Programs combining swimming training with dry-land strength (80-90% of the maximal load) (Girold et al., 2012) or with in-water assisted and resisted training (Girold et al., 2007) have demonstrated to be effective for sprint velocity and were more efficient than swimming alone. This represents an improved ability to generate power on water to reach higher SF and SL (Girold et al., 2012). An increase in maximal SF of 1% to 2% represents an increase of 0.6% to 0.8% in maximal swimming speed

each season (Termin and Pendergast, 2000). Indeed, increases in male's maximal SF and SL from one season to the next had strong association with increases in 200 m freestyle performance (Huot-Marchand et al., 2005) but not with the 100 m and 200 m breaststroke events (Thompson and Cooper, 2003). On the other hand, females tend to increase efficiency over the season. Female swimmers are unable to increase significantly the lean mass as their male counterparts (Anderson et al., 2006). In this sense, the within season improvements in velocity are reached by increasing stroking kinematics, namely the SL.

Within season adaptations on stroking variables are also dependent from individual kinematical characteristics. At least one study included in the present review (Anderson et al., 2006) reported between-individual variations of 2-5% in maximal stroke characteristics over the season. Earlier speculations about this large variability on biomechanical adaptations (Keskinen and Komi, 1993) are now confirmed. It seems that each swimmer uses the most freely chosen combination (e.g. an increased SL and lower SF; or vice versa) to reach higher performances throughout the season.

Seasonal adaptations in SF and SL are also dependent from the type of training program. The high volume programs have been found to increase SL (Costill et al., 1991; Wakayoshi et al., 1993) but not SF (Wakayoshi et al., 1993; Faude et al., 2008). High volume training programs has been reported to inhibit the development of muscular power and strength (Dudley and Fleck, 1987). Because the increase in maximal SF within the season is dependent from those aspects, there is little margin of improvement using this kind of programs. In contrast, swimming at lower speeds allows focusing on stroke phase aspects, and therefore increasing the distance swum per stroke. However, at some point of the season, a maximal SF vs. SL combination is reached. To induce further adaptations they may require new training intensity or a taper period to obtain the benefits of the long distance load.

Studies based on high intensity programs with lower volumes have reported that maximal SF either remained unchanged (Faude et al., 2008) or improved (Termin and Pendergast, 2000) with training. The difference in SF output between studies may also be accounted to the duration of the training programs. Five weeks of intensity training were not sufficient to induce substantial adaptations in SF during 100 m and 400 m front crawl maximal efforts (Faude et al., 2008). On the other hand, the manipulation of SF-velocity curve over four consecutive seasons increased maximal SF in 8% and improved the 100 and 200 yards freestyle velocity (Termin and Pendergast, 2000). The ability to shift to the right the SF-velocity curve by ~10% per season will substantially improve performance (Termin and Pendergast, 2000). High intensity training also promotes increases in maximal SL. At least one study (Termin and Pendergast, 2000) showed a

16% increase in maximal SL after four seasons of high intense training. Thus, high intensity training with lower volumes appears to be more effective in improving stroke characteristics than high volume training. Earlier observations have already reported that performance depends mainly from training intensity and less from volume or frequency (Mujika et al., 1995).

When preparing for a major competition, elite swimmers on regular basis employ significant reductions in weekly training volume and promote high intensities nearly the race pace, often know as the "taper period". There are still few studies regarding biomechanical adaptations during such "period". Two studies (Costill et al., 1991; Anderson et al., 2006) have found increases in SL and slight declines in SF during taper phases within the season. One study (johns et al., 1992) reported that taper did not result in significant alterations either in SF or SL. The intervention duration has an important role on swimmers response to taper (Mujika et al., 1998). Taper phases of the included studies lasted about 10-14 days (Johns et al., 1992) and 3-4 weeks (Costill et al., 1991; Anderson et al., 2006). The time constant of decay of the training load can also affect the swimmers response (Mujika et al., 1998). Weekly volume was reduced in 60-76% throughout taper, which can explain the absence of improvement in biomechanical characteristics of those subjects (Johns et al., 1992). A two week taper during which training volume is exponentially reduced by 41-60% seems to be the most efficient strategy to induce adaptations (Bosquet et al., 2007). Although the taper can be conducted in many ways, there still remain some doubts if this last approach is the most effective way of doing it, and deeper research is needed.

Therefore, further longitudinal investigations in biomechanics should use more complex procedures (e.g. videometric) to expand the analysis to other biomechanical domains. Although being more time consuming, it is necessary to increase the reliability and to improve the quality of the interventions. It is also important to report evidence about other biomechanical variables directly associated with performance (e.g., stroke index, propelling efficiency, index of coordination, drag force, propulsive forces and buoyancy force) and to provide quick practical information for swimmers and coaches to adjust training methods.

Performance

Longitudinal performance assessment can be developed by tracking race times and analyzing ranking positioning for a given period of time. This information is important to help coaches selecting appropriate training methods and to predict chronological points for better results.

Two studies used race times (Costa et al., 2010b) and ranking positioning (Sokolovas, 2006) to analyze the performance progression from childhood to adulthood. It was reported a significant improvement in performance (Costa et al., 2010b) and high variability in ranking positioning (Sokolovas, 2006) from 12 to 18 years old. At adult age, most of the US top-100 swimmers were never ranked in that top at younger ages (Sokolovas, 2006). Added to that, the magnitude of change in 100 m breaststroke performance was not similar between all seasons, reaching high stability at the age of 16 years (Costa et al., 2010b). There seems to be uncertain regarding the determination of the adult competitive level based on result at earlier ages. So, coaches should design the periodization program based on swimmer's growth and maturation process. In addition, coaches should also help early maturing swimmers to keep their sports success in perspective and that maturation process involves until 16-17 years-old in some young athletes.

Another study (Costa et al., 2010a) showed evidences regarding the performance progression during an Olympic cycle. World-Ranked swimmers were able to demonstrate a 3 to 4% of performance improvement in freestyle events between Athens 2004 and Beijing 2008 Olympic games. However, the range of performance improvement was not so obvious through consecutive seasons. Swimmers started to demonstrate high stability in freestyle race times around the third season of the Olympic cycle (Costa et al., 2010a). In order to ensure an Olympics presence they should be near of their best performances in this specific point. Performance improvements were also reported within the last season of an Olympic cycle. The magnitude of improvement in race times of World-ranked swimmers was around 0.6 to 1% in both Sydney 2000 (Pyne et al., 2004) and Beijing 2008 (Costa et al., 2010a) Olympic games season's. Despite being small, those performance enhancements are important in reaching a better ranking positioning throughout the season and to increase the chance to win a medal at the main competition. Most of the swimmers (87%) who won a medal in the Sydney 2000 Olympic games were in the top-10 World-Ranking in that year (Trewin et al., 2004). In this sense, coaches are advised to track the magnitude of performance change and the ranking positioning within the season to ensure an Olympic participation and the possibility to win an Olympic medal.

The magnitude of change in performance within the season seems to be dependent from the type of stroke and the distance swum. Two studies have analyzed the performance variation between two national level competitions. It was reported a performance variation of 0.8 % for international swimmers between national trials and the Olympics (Pyne et al., 2004). On the other hand, it was observed a 1.4% of performance variation in the same event for national

swimmers, participating in two national championships spaced by 20 days (Stewart and Hopkins, 2000). One possible explanation for the differences in the magnitude of change can be the sample characteristics. The less consistency for national swimmers is related to the lower experience in racing than international ones (Pyne et al., 2004). National swimmers also demonstrated less consistent (1.7%) between distances for a given stroke, and least consistent (2.7%) between strokes for a given distance (Stewart and Hopkins, 2000). Thus coaches should be aware that swimmers are stroke specialists rather than distance specialists. Because different distances represent different physiological challengers training should emphasize specific sets concerning a particular stroke and adjacent distances (e.g., 50 and 100 m or 100 m and 200 m, etc) from that stroke.

The last stage of preparation before the main event is the most important phase in peaking for the optimal performance. Two studies (Mujika et al., 2002; Issurin et al., 2008) have analyzed the performance change in the final weeks of preparation leading to the Olympics competition. There were improvements of 2% (Mujika et al., 2002) and 0.6% (Issurin et al., 2008) in race times of swimmers preparing to the Sydney and Athens Olympic Games, respectively. The difference in the magnitude of change can be explained by the characteristics of the sample. Although both studies considered race times from the top level swimming nations with regular presence at the Olympics (e.g. Australia, South Africa, Germany) one of those studies (Mujika et al., 2002) included performances from lower level nations (e.g. Angola, Guam and Singapore). Swimmers in the bottom of the ranking list are able to have a larger improvement than the top ones.

Therefore, further longitudinal interventions regarding exclusively the performance analysis should focus on the prediction approach to other competitive swimming strokes or distances. In addition some attempts should be attempted trying to discriminate genders' differences in a large range of age as possible.

Practical Applications

The scientific evidences reported in this paper may be encouraging for swimmers and coaches. The stability and change in some variables can be a useful tool for training control and performance diagnosis. Based on these scientific evidences, coaches can use submaximal and maximal [La$^-$] data for daily training prescription at the various exercise intensities. Conversely, the reduced changes observed in VO$_2$max and HR within the season suggests that those variables are less informative at least for elite swimmers. Most of technical drills for elite swimmers should focus on increasing SL. Although there are only evidences for male

swimmers, in both genders performance enhancement might also be obtained increasing the SF. On top of that, coaches should identify the swimmer's optimal relationship between SF and SL.

There is a need to rethink the type of training in an attempt to promote further adaptations in elite swimmers. The training intensity seems to be the best way to develop both energetic and biomechanical profiles. Since the majority of the competitive swimming events last less than 3 minutes at high intensity, training programs based mainly on low intensity and high volumes might not be the most suitable. Coaches should design training sets with intensities nearly or similar to those used by the swimmer on main events.

Finally, coaches can also use the magnitude of performance progression and raking positioning data. Those are useful tools for the performance prediction in important competitions and/or throughout swimmers' career.

Future research in swimming should emphasize the use of more complex research designs (e.g., control groups and practical effects) to improve the quality of the studies. Those are procedures used on regular basis in more advanced scientific areas, such as for instance health sciences. Added to that, we tried to explain the need to have further interventions on other swimming events besides those reported above (200 m and 400 m freestyle).

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Chapter 2

Stability of elite freestyle performance from childhood to adulthood

Abstract

Stability of athletic performance is important for practitioners and coaches, since it allows the selection of appropriate training methods and prediction of ages for best results. We performed a longitudinal study of 1694 season-best performances of 242 elite-standard swimmers throughout their careers, from 12 to 18 years of age. Mean stability (descriptive statistics and one-way repeated-measures ANOVA, followed by a Bonferroni post-hoc test) and normative stability (Cohen's kappa tracking index and the Pearson correlation coefficient) were determined for seven consecutive seasons. Performance improvements in all events were observed (14.36–18.97%). Bonferroni post-hoc tests verified changes in almost all events assessed. Cohen's kappa demonstrated low stability (0.17–0.27) in relative performance. Pearson correlations only became high from 15 to 16 years in the 50-m and 100-m events, and from 16 to 17 years in the 200-m, 400-m, and 1500-m events. Our results show that: (a) swimmers should display a substantial improvement (14–19%) to become elite standard as adults, such as at 18 years; (b) 16 is the age at which the ability to predict adult performance increases markedly.

Keywords: *Longitudinal assessment, elite swimmers, stability, prediction*

Introduction

Stability of athletic performance helps researchers to predict the future success of talented young athletes and coaches to select appropriate training methods. Longitudinal studies are required to do this. In swimming science, few such studies exist but those that have been conducted have: (i) related models of training demand with performance enhancement (Hooper et al., 1998; Mujika et al.,1995; Mujika et al., 2002; Termin and Pendergast, 2000; Trinity et al., 2008); (ii) analysed performance variability between competitions, during or between seasons (Costa et al., 2010a, 2010b; Hopkins et al., 2010; Issurin et al., 2008; Pyne et al., 2004; Stewart and Hopkins, 2000); and (iii) related performance progression with ranking (Sokolovas, 2006; Trewin et al., 2004).

It has been suggested that performance assessments based on longitudinal designs are informative, since they allow (Costa et al., 2010b): (i) estimation of the progression and variability of performance during and between seasons; (ii) identification of ages at which predictions of swimmers' performance improve; and (iii) determination of the probability of swimmers reaching finals or winning medals in important competitions. For example, training intensity has been shown to be the key factor in elite swimmers' performance enhancement from season to season (Mujika et al., 1995; Termin and Pendergast, 2000; Trinity et al., 2008). Improvements of approximately 1% in a competition and within the year were necessary to stay in contention for a medal at the Sydney 2000 Olympic Games (Pyne et al., 2004). The third season of the 2004–2008 Olympic cycle was shown to be the time when performance stability increased strongly for Olympic Games performance (Costa et al., 2010b). However, factors that affect adults are different from those that affect children and can vary during swimmers' careers. For instance, aerobic capacity, maximal-intensity exercise, and skill acquisition are influenced by growth and development (Malina, 1994). Hence, there can be wide variation in the age when swimmers approach their maximal individual performance. To the best of our knowledge, there is little information about the prediction of ages for best results. Analyzing the overall trends and individual trajectories of swimming performance for a decade, Hopkins et al. (2010) reported that the age for best performance of New Zealand swimmers was 18.9+1.5 years and 18.7+2.5 years for boys and girls, respectively. It is well known that at some point in a swimmer's career, the rate of performance improvement begins to reduce. For national-standard 100-m breaststrokers over seven consecutive seasons, age 16 was a milestone because performance stability increased strongly for adult-age outcomes (Costa et al., 2010a).

There is a lack of information on the stability and variation of freestyle swimming performance during an athlete's formative years, such as from childhood to adulthood. Thus, the purpose of the present study was to track and analyze freestyle performance during elite-standard swimmers' careers, from 12 to 18 years of age. It was hypothesized that there would be low-to-moderate performance stability in the early years, until a point at which the sensitivity of prediction of adult performance improved markedly.

Methods

Participants

Elite-standard Portuguese male swimmers were assessed in the present study. The inclusion criterion was to be among the top 50 Portuguese male swimmers for short-course performances during the 2006–2007 season in any of the freestyle events recognized internationally (i.e. 50-m, 100-m, 200-m, 400-m, 800-m, and 1500-m events). Exclusion criteria were: (1) a swimmer in the Portuguese top 50, but for whom the authors did not have access to season-best performances for some ages; (2) a swimmer from the Portuguese top 50 but had not swum the event at least once per season from 12 to 18 years; (3) a swimmer from the Portuguese top 50 but not at least 18 years old. In total, 242 elite standard male swimmers were analyzed.

Study design

Retrospective analyses of performance of elite standard male swimmers over seven consecutive seasons were undertaken. Portugal's top 50 list of men in the 2006–2007 season was used to verify inclusion. Performance information was available from an open-access site (www.swimrankings.net). When suitable the Portuguese National Swimming Federation approved collection of the best official results between 12 and 18 years from each swimmer identified in the top 50. A total of 1694 best performances were analyzed over the seven consecutive seasons.

Statistical analysis

The normality of the distributions was assessed with the Shapiro-Wilk test, with the null hypothesis that the population was normally distributed. For all events, data presented a normal distribution. Longitudinal assessment was conducted based on two approaches (Kowalski and Schneiderman, 1992): (i) mean stability and (ii) normative stability. For mean

stability, the mean ± one standard deviation and quartiles were determined for each chronological age and a given event. The relative frequency of performance variation (i.e. percentage of performance improvement) between consecutive ages and overall career improvement was also reported. Data variation was analysed with repeated-measures analysis of variance (ANOVA) followed by a post-hoc Bonferroni test. All assumptions (i.e. independence, normality, and homoscedasticity) to perform the ANOVA analysis were satisfied. Normative stability was investigated via Cohen's kappa (k) ± standard deviation, with a confidence interval of 95% as proposed by Costa et al. (2010a, 2010b) and Bragada et al. (2010). Evaluation of k values was according to Landis and Koch's' (1977) suggestion, where stability is excellent if k ≥ 0.75, moderate if $0.40 \leq k < 0.75$, and low if k < 0.40. The Pearson correlation coefficient between paired performances throughout the seven chronological ages was also determined as another normative stability parameter. Here, stability was considered to be high if high if r ≥ 0.60, moderate if $0.30 \leq r < 0.60$, and low if r < 0.30, as suggested by Malina (2001). These statistical procedures have been used previously in other domains, such as in health (Baumgartner and Roche, 1988; Casey et al., 1994) and physical activity (Glenmark et al., 1994; Pate et al., 1996; Telama et al., 1996), for longitudinal data analysis. Effect sizes were computed based on the eta squared (η^2) procedure, and values interpreted according to Ferguson (2009): no effect if $0 < \eta^2 \leq 0.04$; a minimum effect if $0.04 < \eta^2 \leq 0.25$; a moderate effect if $0.25 < \eta^2 \leq 0.64$ and; a strong effect if $\eta^2 > 0.64$. Statistical significance was set at P ≤ 0.05. Thresholds for assigning qualitative terms to chance of a substantial improvement were as follows: < 0.5 %, most unlikely; 0.5–5%, very unlikely; 6–25%, unlikely; 26–75%, possible; 76–95%, likely; 96–99.5%, very likely; and > 99.5%, most likely (Hopkins, 2007). All statistical procedures were performed using SPSS software (v.13.0, Apache Software Foundation, Chicago, IL, USA), except k values that were determined with Longitudinal Data Analysis software (v.3.2, Dallas, USA).

Results

Figure 1 and Table I show a substantial performance improvement during the seven consecutive seasons in all the freestyle events. One-way repeated-measures ANOVA revealed meaningful variations in the absolute performance in the 50-m freestyle event [$F_{1,35}$ = 769.88; P < 0.01, η^2 = 0.77], 100-m freestyle event [$F_{1,43}$ = 3326.19; P < 0.01, η^2 = 0.73], 200-m freestyle event [$F_{1,43}$ = 16272.81; P < 0.01, η^2 = 0.78], 400-m freestyle event [$F_{1,44}$ = 76665.58; P < 0.01, η^2 = 0.75], 800-m freestyle event [$F_{1,34}$ = 229702.67; P < 0.01, η^2 = 0.65] and 1500-m

freestyle event [$F_{1,90}$ = 678366.26; $P < 0.01$, η^2 = 0.69]. In addition, Bonferroni post hoc tests showed notable differences (P50.01) between all ages in almost all events assessed. The exceptions were the pair-wise comparison between ages 17 and 18 years in all events and between 16 and 18 years in the 800-m and 1500-m events.
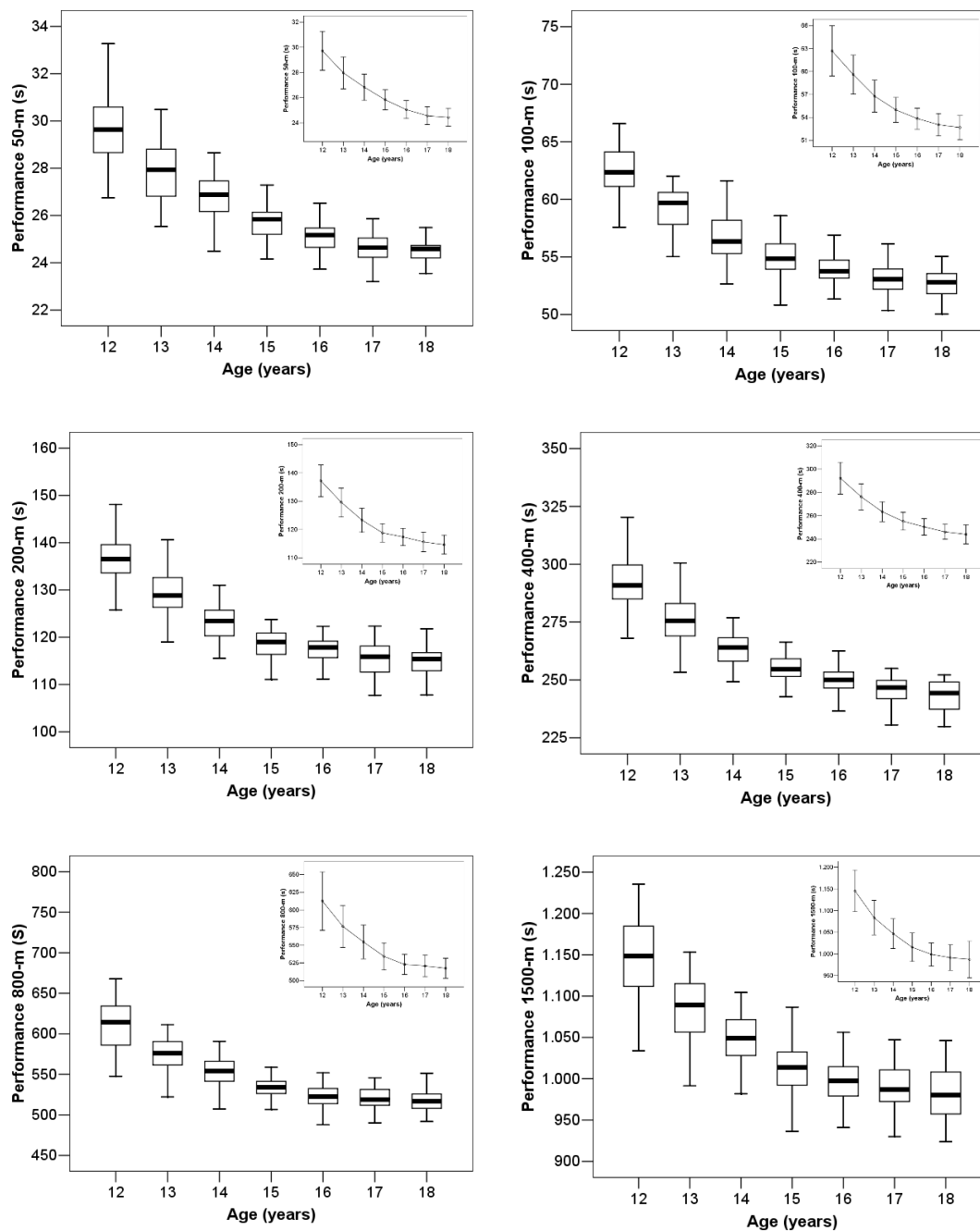
Figure 1. Variations in performance during swimmers' careers, from childhood to adulthood in the freestyle events.

The mean overall career improvement was between 14.36% for the 1500-m event and 18.97% for the 50-m events. The greatest variation was showed to be in the 800-m event (16.13 ± 7.11%). The longer the event distance, the least the overall career improvement.

Table 1. Changes in performance (%) between chronological ages and for overall career in the time frame analyzed.

	Between Chronological Ages (%)						Overall Career (%)
	12-13	13-14	14-15	15-16	16-17	17-18	12-18
50-m	5.85 ± 2.66	4.01 ± 1.91	3.72 ± 2.25	2.97 ± 2.54	1.92 ± 1.911	0.51 ± 1.44	18.97 ± 4.90
100-m	4.89 ± 2.70	4.67 ± 1.96	3.13 ± 1.93	2.02 ± 1.72	1.50 ± 1.64	0.66 ± 1.59	16.86 ± 5.64
200-m	5.54 ± 2.23	4.76 ± 2.79	3.62 ± 2.17	1.19 ± 2.04	1.48 ± 2.63	0.83 ± 1.94	17.43 ± 4.53
400-m	5.47 ± 2.23	4.58 ± 2.38	3.09 ± 1.96	1.85 ± 2.60	1.70 ± 1.99	0.86 ± 2.25	17.54 ± 5.58
800-m	5.74 ± 3.24	3.72 ± 2.49	3.63 ± 2.37	2.08 ± 2.66	0.39 ± 2.20	0.56 ± 2.81	16.13 ± 7.11
1500-m	5.34 ± 2.69	3.35 ± 3.07	2.98 ± 2.57	1.55 ± 2.55	0.75 ± 2.46	0.40 ± 2.96	14.36 ± 5.13

Table 2 presents relative performance stability based on the k values, which express the likelihood of an individual to remain on a given performance trajectory. Stability was rather low for all the freestyle events analysed: 50-m event (k = 0.22 ± 0.05), 100-m (k = 0.27 ± 0.05), 200-m (k = 0.23 ± 0.05), 400-m (k = 0.17 ± 0.05), 800-m (k = 0.24 ± 0.05) and 1500-m (k = 0.17 ± 0.05). Thus, based on overall tracking values from childhood to adulthood, swimmers have a constantly changing performance trajectory. In this sense, a low relative performance stability during their careers should be considered.

Table 2. Cohen's Kappa and 95 % confidence intervals in the freestyle events analyzed.

Event	k	CI 95%
50-m	0.22 ± 0.05	0.17 - 0.27
100-m	0.27 ± 0.05	0.22 - 0.31
200-m	0.23 ± 0.05	0.18 - 0.27
400-m	0.17 ± 0.05	0.12 - 0.22
800-m	0.24 ± 0.05	0.19 - 0.29
1500-m	0.17 ± 0.05	0.12 - 0.22

Table 3 presents the correlation coefficients for pair-wise ages. Correlation coefficients were significant in most paired data (P < 0.01). From childhood to adulthood, correlations ranged from low (r ≤ 0.30) to high (r ≥ 0.60) stability. At younger ages there was lower performance stability when considering its progression to adulthood. However, higher stability in

performance times seems to exist when more strict time frames are used. High stability is achieved from 15 to 16 years in the 50-m event ($r = 0.72$) and 100-m event ($r = 0.68$); from 16 to 17 in the 200-m event ($r = 0.78$), 400-m event ($r = 0.73$) and 1500-m event ($r = 0.70$). The only exception was in the 800-m event, where only moderate stability and prediction were observed.

Table 3. Pearson Correlation Coefficients throughout swimmers' careers in the freestyle events analyzed.

50-m	12	13	14	15	16	17	100-m	12	13	14	15	16	17
13	0.84**	1					13	0.83**	1				
14	0.75**	0.90**	1				14	0.67**	0.87**	1			
15	0.62**	0.73**	0.81**	1			15	0.34*	0.56**	0.83**	1		
16	0.48**	0.48**	0.58**	0.61**	1		16	0.13	0.36*	0.61**	0.80**	1	
17	0.16	0.25	0.35*	0.33	0.74**	1	17	0.08	0,10	0.33*	0.57**	0.81**	1
18	0.31	0.26	0.32	0.28	0.75**	0.87**	18	-0.62	-0.23	0.16	0.37*	0.68**	0.84**
200-m	12	13	14	15	16	17	400-m	12	13	14	15	16	17
13	0.83**	1					13	0.86**	1				
14	0.51**	0.68**	1				14	0.53**	0.78**	1			
15	0.23	0.43**	0.75**	1			15	0.41**	0.57**	0.79**	1		
16	-0.08	0.18	0.47**	0.71**	1		16	-0.02	0.15	0.37*	0.57**	1	
17	-0.10	0.10	0.29	0.56**	0.56**	1	17	-0.08	-0.05	0.15	0.31*	0.72**	1
18	0.10	0.21	0.34*	0.54**	0.48**	0.78**	18	-0.06	-0.04	0.07	0.10	0.53**	0.73**
800-m	12	13	14	15	16	17	1500-m	12	13	14	15	16	17
13	0.87**	1					13	0.75**	1				
14	0.61**	0.86**	1				14	0.49**	0.59**	1			
15	0.54**	0.76**	0.80**	1			15	0.34*	0.34*	0.66**	1		
16	0.18	0.43*	0.59**	0.64**	1		16	0.01	0.05	0.43**	0.61**	1	
17	0.06	0.29	0.47**	0.51**	0.68**	1	17	0.04	0.09	0.37*	0.48**	0.62**	1
18	-0.12	-0.03	0.12	0.11	0.45**	0.48**	18	0.20	0.26	0.30	0.44**	0.49**	0.70**

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

Discussion

The aim of this study was to track and analyse freestyle performance during elite-standard swimmers' careers, from 12 to 18 years of age. There was substantial performance improvement over the period analysed. Based on tracking values for overall career, relative swimming performance stability was low. Based on more strict time frames, the age of 16 is the chronological point at which the ability to predict adult performance increases markedly.

One way repeated-measures ANOVA revealed meaningful variations in absolute performance throughout swimmers' careers. Bonferroni post-hoc tests confirmed notable improvements in all freestyle events. This same phenomenon has been reported previously in studies describing

the individual trajectories (Hopkins et al., 2010) and performance stability (Costa el al., 2010a) of elite young to senior swimmers. Throughout children's formative years, a notable evolution in motor learning skills is observed (Mechsner et al., 2001). Maturation of the central nervous system enables acquisition of sport-specific tasks and tends to produce better results (Fogassi et al., 2005). The maturation process also results in an annual improvement in strength (Beunen and Malina, 1988) from childhood to adolescence. The greatest rate of increase for males occurs about 12–15 months after the appearance of peak height (Bloomfield et al., 1990). Available literature suggests that children can improve muscle strength and aerobic fitness through resistance training. Meta-analysis showed that typical gains in muscle strength were approximately 13–30% greater with resistance training than that which is expected from growth and maturation (Falk and Tenenbaum, 1996). In addition, specific aerobic training in swimming effectively increases such capacity above the limits attributed to the age corresponding to the specific period of growth (Baxter-Jones and Helms, 1993). Regarding physical development, multivariate model analysis has identified the anthropometric characteristics of males to be the most suitable variables to predict performance in young swimmers (Saavedra and Escalante, 2010). At least two longitudinal studies reported that improvements in swimming performance during two consecutive seasons were mainly related to increases in physical determinants during growth (Latt et al., 2009a). Thus in the future there is a good chance to assess hypothetical covariance between swimming performance and the growth/maturation process throughout athletes' formative development.

For a 95% confidence interval, the k value (Table 2), used to express relative performance stability, was low for all events analysed. Similar data (k = 0.38 ± 0.05) were reported for a 7-year time frame of 12–18 years in the 100-m breaststroke event (Costa et al., 2010a). Intra-individual changes suggested that swimmers were unable to maintain their relative individual positions within a performance trajectory during such a long time frame. Thus, from childhood to adulthood, swimmers have a constantly changing performance trajectory. Most US top 100 swimmers at ages 10–11 years did not become adult elite swimmers (Sokolovas, 2006). Often, early maturing athletes experience more early success than their late maturing peers due to a physical growth advantage rather than enhanced skills or abilities. On a regular basis, those athletes tend to have a higher more stable performance trajectory than later matures. However, at some point in their careers late matures often catch up to, or even exceed early maturers. Besides maturation and growth there are other factors that might impose low stability on a performance trajectory: (1) an acute or a chronic injury (Wolf et al., 2009); (2) illness (Hellard et al., 2011); (3) overtraining (Pelayo et al., 1996); (4) inappropriate training

volume (Sokolovas, 2006); and (5) better support and training conditions. Thus future research should attempt to identify the influence of internal and external training loads on swimming performance from a child to adult/elite swimmer and how they determine an athlete's competitive standard at adult ages.

The correlation coefficients in Table 3 can be interpreted based on two different points of view: (1) diagonal perspective (e.g. analysing the correlations between chronological ages, one by one) and (2) horizontal perspective (e.g. considering the correlations between each chronological age and 18 years). On a diagonal interpretation, the correlation coefficients tend to be high when considered year by year. When more strict time frames are used, swimming performance stability and prediction increase (Costa et al., 2010b). For two consecutive seasons, high stability and prediction were observed in both young female swimmers (Latt et al., 2009b) and young male swimmers (Latt et al., 2009a) in the 400-m freestyle event.

On a horizontal perspective, the correlations coefficients between performances at 12 and 13 years and those at 16, 17, and 18 years presented a low-to-moderate value. A similar profile was observed from 12 to 18 years for 100-m breaststroke performance (Costa et al., 2010a). Malina (2001) reported that from childhood to adolescence the inter-correlations over a 3-year period are between 0.30 and 0.50 and the trend is to increase after adolescence. Moreover, the identification of talented performers is not possible before the peak growth period occurs (Blanksby et al., 1986). Usually the growth spurt is reached around the age of 14 years. Most of the pair wise correlations only became $r \geq 0.60$ at age 16 years. High stability is achieved from 15 to 16 years in the 50-m event and 100-m event, and from 16 to 17 years in the 200-m event, 400-m event, and 1500-m event. Thus it appears that there is no reliability in the prediction of adult performance based on athletes' best performances at earlier ages, such as 12–13 years. However, age 16 can be considered the age at which absolute performance stability increases and, therefore, the ability to predict swimmers' likely adult standard also increases.

When analysing individuals' mean career improvement (Table 1), the mean percentage of improvement decreases as those individuals reach adulthood. For each season that passes by, swimmers get closer to their peak personal performance. The best performances are usually achieved during the final stage of an athlete's competitive career (Smith, 2003). For a New Zealand male swimmer, Hopkins et al. (2010) reported that the age for peak performance was 18.9 ± 1.5 years. Platonov (2005) also reported male swimmers' maximal individual performance to be between 18 and 19 years for short distance specialists (50 m, 100 m, and 200 m) and between 17 and 18 years for long-distance specialists (400 m and 1500 m). For

world-class swimmers, it has been reported that age 15–16 the age to achieve the best individual performance in long distance events (Malina and Bouchard, 1991; Sokolovas, 1998).

A practical implication for practitioners (e.g. swimming coaches) is that early success should be avoided. Coaches must focus on educating swimmers based on growth and maturation cycles. For that purpose, they should help early maturing individuals keep their success in perspective, and ensure later maturing individuals are involved until the age of 16 years. Beginning at age 16, swimmers are close to their best personal performance and the prediction of adult competitive ability increases strongly.

In conclusion, swimmers should display a substantial improvement (14–19%) from childhood to adulthood in all freestyle events to become elite standard adult swimmers, such as at age 18 years. In addition, coaches should set the age of 16 years as the age at which the ability to predict adult competitive level increases markedly.

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Chapter 3

Tracking the performance of World-Ranked swimmers

Abstract

Tracking the swimming performance is important to analyze its progression and stability between competitions and help coaches to define realistic goals and to select appropriate training methods. The aim of this study was to track world-ranked male swimmer's performance during five consecutive seasons (from 2003/2004 to 2007/2008) in Olympic freestyle events. An overall of 477 swimmers and 2385 season best performances were analyzed. FINA's male top-150 rankings for long course in the 2007-2008 season were consulted in each event to identify the swimmers included. Best performances were collected from ranking tables provided by the National Swimming Federations or, when appropriate, through an internet database (www.swimranking.net). Longitudinal assessment was performed based on two approaches: (i) mean stability (descriptive statistics and ANOVA repeated measures, followed by a Bonferroni post-hoc test) and; (ii) normative stability (Pearson Correlation Coefficient and the Cohen's Kappa tracking index). Significant variations in the mean swimming performance were observed in all events between all seasons. Performance enhancement was approximately 0.6 to 1 % between seasons leading up to the Olympics and approximately 3 to 4 % for the overall time-frame analyzed. The performance stability based on overall time-frame was moderate for all freestyle events, except in the 50-m ($k = 0.39 \pm 0.05$) where it was low. Self-correlations ranged between a moderate ($0.30 \leq r < 0.60$) and a high ($r \geq 0.60$) stability. There was also a performance enhancement during all five seasons analyzed. When more strict time frames were used, the analysis of swimming performance stability revealed an increase in the third season. So, coaches should have a long term view in what concerns training design and periodization of world-ranked swimmers, setting the third season of the Olympic Cycle as a determinant time frame, due to performance stability until Olympic Games season.

Keywords: *Longitudinal assessment, freestyle, swimming, elite swimmers*

Introduction

The majority of the studies in swimming "science" have a cross-sectional character. Indeed, they do not consider performance stability and change as result, for example, of individual development, new training methods and/or technological sophistication. On the other hand, the longitudinal approaches regarding competitive swimming are few. Some papers aimed to obtain comprehensive knowledge about the role of bioenergetics (Pyne et al., 2001; Thompson et al., 2006) and biomechanics (Craig et al., 1985; Arellano et al., 1994; Huot-Marchand et al., 2005) issues in performance enhancement. Others tried to establish relationships between these two domains and swimming performance (Anderson et al., 2008; Latt et al., 2009a; Latt et al., 2009b). However, there has been little research focused on the annual performance progression (Stewart and Hopkins, 2000; Pyne et al., 2004; Trewin et al., 2004).

It was demonstrated that the longitudinal performance assessment is important to help coaches to define realistic goals and training methods (Pyne et al., 2004). Longitudinal assessment can therefore be developed by tracking the swimmers' performance for a given period of time, analyzing its progression between competitions and/or seasons. This information can be used to: (i) describe and estimate the progression and the variability of performance during and between seasons; (ii) find hypothetical chronological points determinant to predict swimmer's performance throughout his/her career or a given time frame and; (iii) determine swimmer's probability to reach finals or win medals in important competitions.

Swimming has been experiencing a very quick development in all events, since world records have been broken so often. Moreover, its maximal expression was achieved in the time frame between the Athens 2004 and Beijing 2008 Olympic Games. However, no scientific study until now has attempted to quantify and/or systematically describe these performance enhancements over the last few seasons.

A small number of attempts were made to track competitive swimmers performance. Pyne et al. (2004), in a 12 month time-frame study, made an attempt to understand the swimmers performance behaviour leading up to the 2000 Olympic Games. They reported that to stay in contention for a medal, a Sydney's 2000 Olympic swimmer should improve his/her performance by approximately 1 % within a competition and by approximately 1 % within the year leading up to the Olympics. Authors also stated that presumably an additional enhancement of approximately 0.4 % would substantially increase the swimmer's chances of winning a medal (Pyne et al., 2004). Some attempts were made to predict swimming

performance as well. Trewin et al. (2004) verified that by examining the relationship between world-ranking and the 2000 Olympic performance, most of the Olympic medallists (87 %) had a top-10 world-ranking in the Olympics year. Sokolovas (2006) reported that half of the American 100-top swimmers with 18 years of age have never been in that top in younger ages, such as, before 10 and 12 years. Nevertheless, appears not exist any research so far analyzing the change and stability of world-ranked swimmers' performance using the tracking approach. The purpose of this study was to analyze the stability and change of male world-ranked swimmers' performance in freestyle Olympic events for five consecutive seasons, namely between the 2004 and the 2008 Olympic Games.

Methods

Procedures

It was considered as inclusion criteria to be a FINA's male top-150 world-ranked swimmer for long course during the 2007-2008 season, in any of the freestyle events presented in the Olympic calendar (the 50m, 100m, 200m, 400m and 1500m events). On the contrary, an exclusion criteria was considered: (i) to be a swimmer from the FINA's top-150, but authors did not have access to season best performance in the five consecutive seasons; (ii) to be a swimmer from the FINA's top-150 but not having swum the event at least one time per season from 2003-2004 to 2007-2008 for some reason. Overall of 477 swimmers and a total of 2385 season best performances were analyzed. Ranking tables provided by the National Swimming Federation of each swimmer identified in the FINA's top-150 were also used to collect the season best performance between 2003-2004 (Athens's Olympic Games season) and 2007-2008 (Beijing's Olympic Games season). When suitable or appropriate, race times were also collected from a public swimming database (www.swimrankings.net, August 2009).

Statistical analysis

The normality of the distributions was assessed with the Shapiro-Wilk test, considering as null hypothesis that the population is normally distributed. For all events, data presented a normal distribution. Longitudinal assessment was made based on two approaches: (i) mean stability; (ii) normative stability. For mean stability, mean plus one standard deviation and quartiles were computed for each season and a given event. The relative frequency of performance variation (i.e. percentage of performance improvement) between consecutive seasons and between first and last season was also reported. Data variation was analyzed with ANOVA

repeated measures followed by a post-hoc test (Bonferroni test). All assumptions to perform the ANOVA analysis were taken into account (i.e., independence, normality and homoscedasticity). Normative stability was analyzed with the Cohen's Kappa (k) plus one standard deviation, with a confidence interval of 95 %. The qualitative interpretation k value was made according to Landis and Koch (1977) suggestion, where the stability is: (i) excellent if k ≥ 0.75; (ii) moderate if $0.40 \leq k < 0.75$ and; (iii) low if k < 0.40. The Pearson Correlation Coefficient between paired performances throughout the five seasons was also computed as another normative stability parameter. Qualitatively, stability was considered to be: (i) high if r ≥ 0.60; (ii) moderate if $0.30 \leq r < 0.60$ and; (iii) low if r < 0.30, as suggested by Malina (2001). All statistical procedures were computed using 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

A performance variation and improvement during the five consecutive seasons in all the freestyle events is observed in both figure 1 and table 1. Moreover, ANOVA repeated measures revealed significant variations in the swimming performance in the 50m event [$F_{1,93}$ = 57.91; P < 0.01, power = 1.00], 100m event [$F_{1,97}$ = 105.34; P < 0.01, power = 1.00], 200m event [$F_{1,98}$ = 55.45; P < 0.01, power = 1.00], 400m event [$F_{1,91}$ = 67.89; P < 0.01, power = 1.00] and 1500m event [$F_{1,90}$ = 91.81; P < 0.01, power = 1.00]. In addition, Bonferroni post-hoc tests verified significant differences between all seasons in all freestyle events (P < 0.01). The only exception was for the pair wise comparison between the third and fourth seasons in the 400m event which was not-significant. The mean improvement between seasons ranged from 1.12 % for the 50m and 0.64 % to the 200m freestyle event. Overall mean performance improvement was between 4.48 % for the 50m and 2.54 % for the 200m.
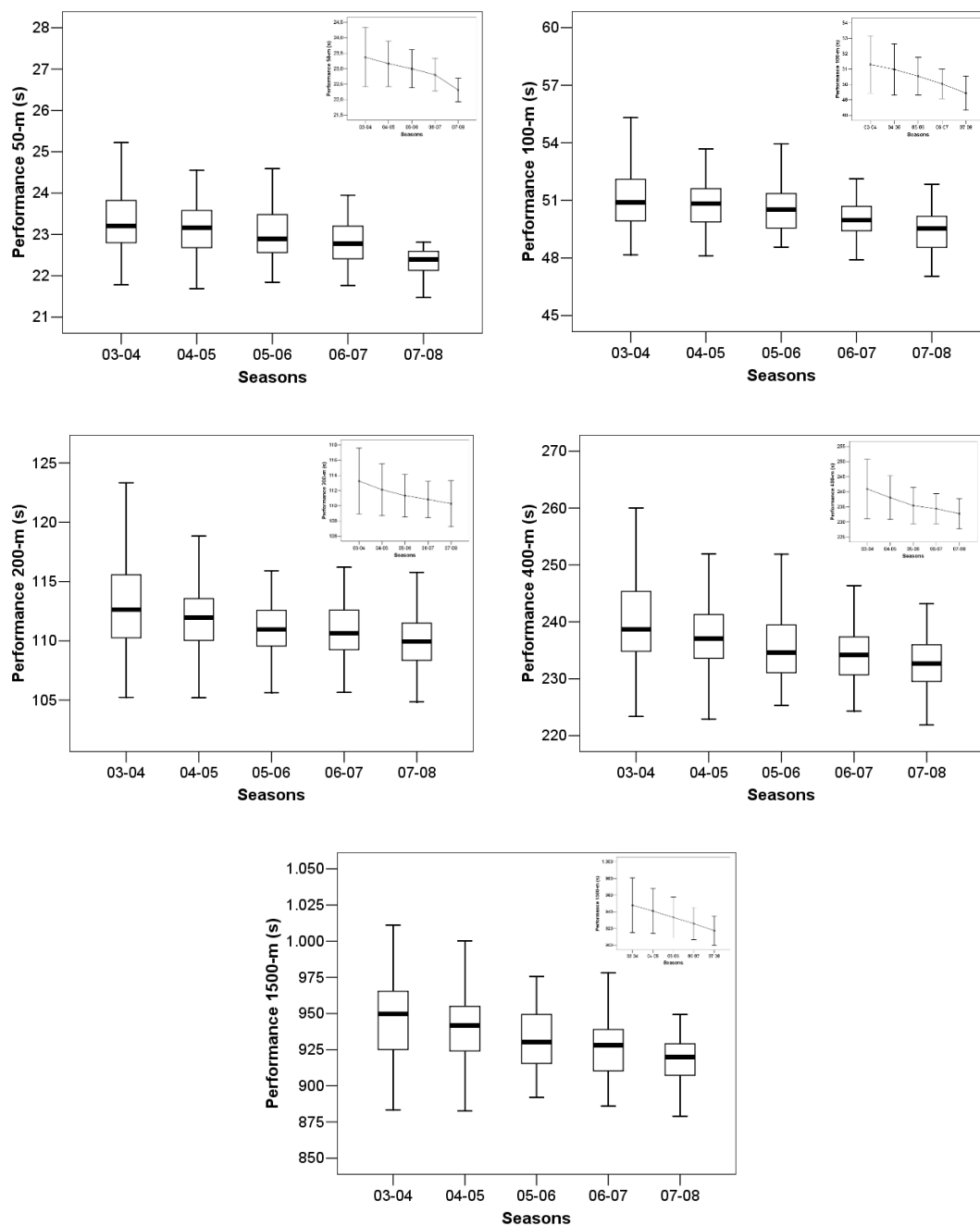
Figure 1. Variation of swimming performance during five consecutive seasons in the freestyle events.

Table 2 presents the swimming performance stability based on the k value, which expresses the stability throughout the overall seasons analyzed. And this was rather low in the 50m event (k = 0.39 ± 0.05). However, in the 100m (k = 0.46 ± 0.05), 200m (k = 0.49 ± 0.04), 400m (k = 0.43 ± 0.05) and 1500m (k = 0.44 ± 0.05) events, it was moderate. So, based on overall tracking values of the five consecutive seasons, a moderate swimming performance stability and prediction can be considered.

Table 1. Changes (%) in mean performance time between seasons and in the overall time frame analyzed. Data are means (± SD).

	Between Seasons				Overall time frame
	03/04 04/05	04/05 05/06	05/06 06/07	06/07 07/08	03-08
50m	0.84 ± 2.08	0.68 ± 1.71	0.83 ± 1.62	2.13 ± 1.79	4.48 ± 3.78
100m	0.60 ± 1.53	0.82 ± 1.67	0.96 ± 1.29	1.19 ± 1.43	3.58 ± 3.37
200m	0.94 ± 1.64	0.66 ± 1.56	0.46 ± 1.28	0.48 ± 1.65	2.54 ± 3.40
400m	1.14 ± 1.78	1.08 ± 1.50	0.42 ± 1.64	0.68 ± 1.53	3.33 ± 3.73
1500m	0.70 ± 1.44	0.79 ± 1.53	0.77 ± 1.80	0.89 ± 1.39	3.16 ± 2.90

Table 2. Cohen's Kappa values (K) and 95 % confidence intervals (CI) in the freestyle events analyzed.

Event	k	CI 95%
50-m	0.39	0.34 - 0.43
100-m	0.46	0.42 - 0.51
200-m	0.49	0.45 - 0.54
400-m	0.43	0.38 - 0.48
1500-m	0.44	0.39 - 0.48

Table 3 presents the Pearson Correlation Coefficient values for pair wised seasons between 2003-2004 and 2007-2008. Pearson correlations were significant in all paired data ($P < 0.05$). It can be stated that throughout the five seasons, correlations ranged from a moderate ($0.30 \leq r < 0.60$) to a high ($r \geq 0.60$) stability. Indeed, most of the pair wise correlations were $r \geq 0.60$. A high stability in what concerns swimming performance in world-ranked swimmers when more strict time frames are used seems to exist. Doing an analysis based on the peak performance season (i.e., 2007-2008 season, Beijing Olympic Games), we verify when closer the swimmers gets to the 2008 Olympics, higher is the performance stability. High stability is achieved from the second to the third season in the 100m event ($r = 0.65$), 200m event ($r = 0.63$) and 1500m event ($r = 0.61$); from the third to fourth season in the 50-m event ($r = 0.63$) and 400m event ($r = 0.73$). So, during the first season of the Olympic cycle there was a lower stability of swimming performance when considering its progression until the Olympic Games season. Thus, the season previous to the Olympic Games is determinant to achieve high performances.

Table 3. Pearson Correlation Coefficients throughout all season's analyzed in the freestyle events.

50-m	03-04	04-05	05-06	06-07	07-08	100-m	03-04	04-05	05-06	06-07	07-08
03-04	1					03-04	1				
04-05	0.85*	1				04-05	0.90*	1			
05-06	0.65*	0.83*	1			05-06	0.75*	0.85*	1		
06-07	0.49*	0.65*	0.79*	1		06-07	0.64*	0.73*	0.84*	1	
07-08	0.28*	0.46*	0.55*	0.62*	1	07-08	0.37*	0.49*	0.65*	0.76*	1
200-m	03-04	04-05	05-06	06-07	07-08	**400-m**	03-04	04-05	05-06	06-07	07-08
03-04	1					03-04	1				
04-05	0.90*	1				04-05	0.90*	1			
05-06	0.73*	0.85*	1			05-06	0.71*	0.86*	1		
06-07	0.62*	0.76*	0.85*	1		06-07	0.49*	0.68*	0.76*	1	
07-08	0.47*	0.59*	0.63*	0.79*	1	07-08	0.35*	0.46*	0.58*	0.73*	1
1500-m	03-04	04-05	05-06	06-07	07-08						
03-04	1										
04-05	0.91*	1									
05-06	0.72*	0.84*	1								
06-07	0.44*	0.61*	0.69*	1							
07-08	0.49*	0.58*	0.61*	0.75*	1						

* P < 0.05; ** P < 0.01

Discussion

The purpose of this study was to analyze the stability and change of male world-ranked swimmers' performance in freestyle Olympic events during five consecutive seasons from 2003/2004 until 2007/2008. There was a clear performance enhancement over the period of time analyzed. Based on overall tracking values of five consecutive seasons, swimming performance stability was moderate. When more strict time frames were used, swimming performance stability increased starting at the third season of the Olympic cycle.

The ANOVA repeated measures revealed significant variations in the swimming performance throughout the five seasons in all events. Bonferroni post-hoc tests confirmed significant performance enhancement over the period of time analyzed in all freestyle events, except for the pair wise comparison between the third and fourth season in the 400m event. Similar data was reported by Anderson et al. (2008) for a 3.6 ± 2.5 years. The performance enhancement over the period of time analyzed might be associated to some scientific highlights such as the kineanthropometrical characteristics (Zamparo et al., 1996), psychological factors (Robazza et al., 2008), energetic profile (Fernandes et al., 2006), biomechanical/technical ability (Barbosa et al., 2008), hydrodynamics (Kjendlie et al., 2008: Silva et al., 2008), genetic background (Costa et al., 2009) or nutritional issues (Zajac et al., 2009), all of which have been recently reported in the literature.

One fact consistently shown is that training and periodization procedures of swimmers are carefully designed to achieve the peak performance in the most important competitions (Aspenes et al., 2009). Swimmers preparing for the 2000 Olympics Games obtained a 2.2 % performance improvement during the final 3-weeks of their preparation (Mujika et al., 2002). Consequently, the model of training load reduction adopted has a higher effect on the swimmers performance. Yet, several researchers also pay attention to other training issues that can enhance swimming performance, such as the warm-up (Zochowski et al., 2007), the swim drills (Konstantaki et al., 2008) or the type of recovery between bouts (Toubekis et al., 2008). We can also speculate that this better coaching, together with better funding support, allows swimmers to have better training conditions, and might, in some cases, contribute to a higher professional environment to achieve better performances.

Another explanation for this performance enhancement can be the technological sophistication around the swimming suits over this specific period of time. It is known that swimsuits, covering large parts of the swimmer's body with special materials, might improve performance. The type of suit materials, such as polyurethane, the methods to sew the materials pieces, suit types and sizes, the effect of swimming suits upon wobbling body masses, and the body compression might explain the major advantages of wearing it (Marinho et al., 2009). However, there are no independent scientific reports about the effects of these swimming suits on performance.

For a 95 % interval confidence (IC), the Cohen's Kappa data, expressing the stability throughout the overall period of time analyzed, was in fact moderate. Based on the five consecutive seasons analyzed, it is clear that swimmers' performance stability is quite difficult to maintain at a high level. This moderate stability and prediction might be associated to the different periods in the swimmer's career time plan. For each event and for the period of time analyzed, some swimmers are closer to their careers' top-level, while others did not yet achieve the career top-level and the remaining ones are at the end of their careers. Moreover, there are several episodes that can also play a major role in the performance stability during a five year time frame, such as an acute or a chronic injury (Bak, 1996). Illness is experienced by almost 90 % of swimmers at some point of the career (Fricker et al., 2000) affecting somehow their performance. Most of the American elite level swimmers at the age of 18 were unknown in the 100-top at younger ages, such as 10-12 years old (Sokolovas 2006). In this sense, it is possible that with increasing time frame analysis, the stability level might decrease.

For all events, most of the pair wise correlations were r ≥ 0.60. So, when stricter time frames are used, higher performance stability can be considered. Indeed, for a two consecutive

season's period, it was verified that a high performance stability and prediction can be obtained in both young female swimmers (Latt et al., 2009a) and young male swimmers (Latt et al., 2009b) at the 400m freestyle events. During the first season of the Olympic cycle there is a lower performance stability based on the Olympic Games season. This data suggests that several world-ranked swimmers take some critical decisions at the beginning of a new Olympic cycle, such as: (i) they adopt a longer resting period between the fourth season of a Olympic cycle and the first season of the new one, mainly for physical and psychological reasons, which reduces the chances of performance enhancement; (ii) they try to make deeper changes in their technique to enhance swimming efficiency or; (iii) they shift their goals to new swimming events, requiring the adaptation to new training models.

When the analysis is made based on the 2007-2008 season (Beijing Olympic Games), a deceleration is observed starting at the third season, as the performance stability increases. High stability is achieved from the second to third season in the 100m, 200m and 1500m events; from the third to fourth season in the 50m and 400m events. These data is somewhat in accordance to the fact that an Olympic swimmer should improve his/her performance by approximately 1 % within the year leading up to the Olympics (Pyne et al, 2004). Indeed, in this research it was found that the mean improvement between seasons ranged from 1.12 % for the 50m to 0.64 % in the 200m freestyle event. Plus, the mean improvement between seasons ranged between 1.12 % for the 50m and 0.64 %, for the 200m freestyle event. So, it seems that our data is somewhat in accordance with the Pyne's et al. (2004) results.

Examining the relationship between world-ranking swimmers in the Olympics season, with the 2000 Olympic Games performance, most Olympic medallists (87 %) had a top-10 world-ranking in that year (Trewin et al., 2004). In this sense, the season previous to the Olympic Games is determinant to achieve high performances in most events.

Conclusion

World-ranked swimmers' performance displayed great improvement between the 2003/2004 and 2007/2008 seasons in all freestyle events. World-ranked swimmers' performance increased approximately 0.6 % to 1% between seasons, and 3 % to 4% in the overall time frame. The stability and prediction of swimmers' performance based on overall Olympic cycle period was therefore moderate. When more strict time frames were used, swimming performance stability increased starting at the third season of the Olympic cycle.

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Chapter 4

Energetic and biomechanical relative contribution for longitudinal

swimming performance

Abstract

The aim of this study was to assess the pooled and individual response of male swimmers to training, and to identify the major energetic and biomechanical predictors of performance. Elite subjects (n = 9) performed six testing sessions over a two season period. An incremental test was applied to obtain the swimming velocity at 4 mmol L^{-1} of blood lactate (V_4) and the peak blood lactate (La_{peak}) as energetic, and the stroke frequency (SF), stroke length (SL), stroke index (SI) and propelling efficiency (η_p) as biomechanical selected variables. Performance was determined based on official time's lists of 200 m freestyle event. There were no significant changes in V_4, SF, SL, SI and η_p. Only the La_{peak} significantly changed (p = 0.05) within and between seasons (TP_1 = 9.9 ± 2.4 mmol.l^{-1}; TP_2 = 11.4 ± 2.6 mmol.l^{-1}; TP_3 = 13.1 ± 3.3 mmol.l^{-1}; TP_4 = 10.9 ± 2.9 mmol.l^{-1}; TP_5 = 12.9 ± 2.0 mmol.l^{-1}; TP_6 = 13.0 ± 2.7 mmol.l^{-1}). The swim performance improved slightly over the two consecutive seasons. High autocorrelations were found between similar time periods from separate seasons. There was a high variability in the swimmer's response to the training. Hierarchic linear modeling showed that each unit of change in V_4, SF and SL, represented a positive effect on performance of -0.10 s, -1.20 s and -0.36 s, respectively. Elite male swimmers demonstrate slight changes on their performance, and energetic and biomechanical profiles within and between seasons. Each swimmer has a singular way responding to the training load applied. Improvements on performance can be accomplished by manipulating the V_4, SF and SL.

Keywords: *predictors, annual changes, training, tracking, testing*

Introduction

The ability to monitor changes within and between seasons provides fundamental information for coaches on the swimmers' response to their training periodization. Energetic and biomechanical data are crucial to determine the effectiveness of the previous load and therefore adjust training methods in order to enhance performance. Added to that, the identification of the factors that might predict, with higher accuracy, the swimming performance is the most important aim for coaches and researchers in swimming science. In the last few decades, high importance was given to the energetic and biomechanic domains. Among the energetic variables assessed on a regular basis are the velocity at 4 mmol of blood lactate levels (V_4) and the maximal blood lactate concentrations after exercise (La_{peak}).

The assessment of V_4 and La_{peak} status throughout the season has trivial importance in determining the aerobic and anaerobic fitness of the swimmers, respectively. It was demonstrated that the aerobic fitness of elite swimmers can be improved with training. There is a small but meaningful increase in V_4 of ~1.5% within the season (Pyne et al., 2001; Anderson et al., 2006; Costa et al., 2012). Generally, most of those gains occur in the early months, due to an increase in training volume (Sharp et al., 1984; Ryan et al., 1990). Adaptations in anaerobic fitness are also evident throughout the season. Substantial increases (from ~12% to ~27%) in La_{peak} have been reported for elite male swimmers (Termin and Pendergast, 2000; Anderson et al., 2006; Faude et al., 2008). Conversely, those changes seem only to occur from mid phases until the season's end (Faude et al., 2008). Most of the longitudinal evidences regarding biomechanical factors were based on the stroke frequency (SF) and stroke length (SL) adaptations. Indeed, some inconsistent findings between studies were presented. Anderson et al. (2006) reported that male swimmers tend to increase SF and decrease SL in 1% to 2% each year. On the other hand, Costa et al (2011a) determined within season increases (~2%) in SL and decreases (~1.3%) in SF for international and national swimmers. Swimming researchers have also focused their attention on other biomechanical measures, such as the stroke index (SI) and the propelling efficiency (η_p). Both variables showed to increase with training, namely in the last stage of the season (Costa et al., 2012). Nevertheless, most of these studies only tracked performance, energetic and biomechanical variables during one single season. It seems there still remains a lack of scientific evidence regarding swimmer's adaptations throughout two or more competitive seasons. Based on the state of the art about longitudinal assessment of elite swimmers, changes occur very smoothly. It is quite difficult to observe in this population meaningful increases on performance,

energetic or biomechanical profiles in one single season. Therefore, there is a chance to track down the swimmer's adaptation to training throughout longer time periods. Over a period of two or more seasons it might be more suitable to have a better understanding of the adaptations that occur in such high-level athletes.

Most of the research designs and data analysis procedures are based on pooled data from a given subject´s sample. However, elite level coaches do not design training routines for "pooled" swimmers. They design periodization and training procedures on individual basis, according to individual characteristics of each one of their swimmers. So, the assessment of individual trends is another important topic of training diagnosis and should also be for sport performance researchers. With the identification of the swimmer's individual combination on energetic and biomechanical aspects it becomes easier to adequate prescription for further adaptations. At the moment one single study has examined individual responses with such purpose in competitive swimming. Authors reported a large variability between gender and competitive level throughout several years of training (Anderson et al., 2006). However, it still remains the doubt if subjects with similar competitive level present the same energetic and biomechanical responses to training within the season.

Another topic of interest for coaches and researchers is to determine the relationships between performance and selected energetic and biomechanical variables. Recent cross sectional evidences suggested strong links between the three domains in both young (Barbosa et al., 2010a) and elite swimmers (Barbosa et al., 2010b). However, the methods used to assess those relationships were based on exploratory (co-variance or regression models) or confirmatory (structural equation modelling) data analysis. One more accurate approach for longitudinal designs is to compute a hierarchic linear model (HLM). The HLM creates a hierarchical structure like a "tree", being able to identify the energetic and biomechanical variables as performance changing predictors. This approach has been already used in other competitive sports (Bragada et al., 2010) and other scientific areas (Lopes et al., 2011) for that purpose. Nevertheless, it was never attempted in swimming science, and taking elite swimmers as subjects.

The aim of this study was to: (i) assess the pooled and individual response of male swimmers to training over two consecutive seasons and; (ii) identify the major energetic and biomechanical predictors of performance. It was hypothesized: (i) an improvement on performance, energetic and biomechanical variables with high variability in the individual response within and between seasons and; (ii) positive effects from V_4 and SL on competition performance.

Methods

Subjects

Twelve elite male simmers were recruited to participate in the present study. Three swimmers were excluded because of an acute muscle-skeletal injury (n = 1), changed to another swimming team (n = 1) and withdrawal from swimming career (n = 1). A total of nine swimmers (20.0 ± 3.54 years old; 1.79 ± 0.07 m of height; 71.34 ± 8.78 kg of body mass; 22.35 ± 2.02 kg m^{-2} of body mass index; 1.86 ± 0.07 m of arm span; 116.22 ± 4.99 s of personal record in the 200 m long course freestyle event) were considered for further analysis. The elite nature of the subjects is indicated by the presence in Athens 2004 Olympic Games and Melbourne 2007 World Swimming Championships (n = 1), Rome 2009 World Swimming Championships (n = 2) and 2010 LEN Multinations Junior Meet (n = 1) representing their National Swimming Team. Collectively, the other half of the group (n = 5) were top 20 nationally-ranked in the 200 m freestyle event. All swimmers gave their written informed consent before participation, and procedures had the approval from the scientific board of the Polytechnic Institute of Bragança.

Study Design

The nine swimmers were studied in six occasions (n = 54 tests, six tests per swimmer, spaced three months each) over two consecutive years of training (2009-2010 and 2010-2011 seasons). The six tests were conducted at the end of the following time periods: (i) October-December 2009 (TP$_1$); (ii) January-March 2010 (TP$_2$); (iii) April-June 2010 (TP$_3$); (iv) October-December 2010 (TP$_4$); (v) January-March 2011(TP$_5$) and; (vi) April-June 2011 (TP$_6$). In the time period before tests the swimmers completed a full training preparation. Weekly training volume (Figure 1) averaged 44 ± 7 km wk^{-1} and 45 ± 6 km wk^{-1} for the first and second seasons, respectively. Swimming training generally consisted in nine sessions per week involving low, medium and high aerobic tasks, intense sprint work and technical drills. There was an increase in training intensity from the first to the second season namely in: (i) intensity corresponding to their aerobic capacity (2009-2010: 2.02 ± 0.42 km wk^{-1}; 2010-2011: 2.73 ± 0.74 km wk^{-1}); (ii) intensity corresponding to their aerobic power (2009-2010: 1.22 ± 0.21 km wk^{-1}; 2010-2011: 1.65 ± 0.14 km wk^{-1}) and; (iii) anaerobic capacity training (2009-2010: 0.94 ± 0.54 km wk^{-1}; 2010-2011: 1.04 ± 0.26 km wk^{-1}). In the day prior to data collection, the swimmers completed a low intensity training session in order to avoid data bias due to fatigue.
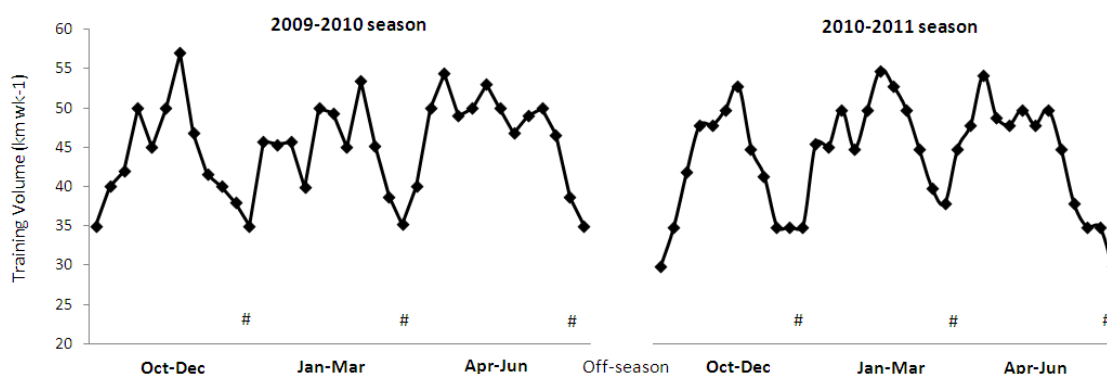
Figure 1. Total weekly volume throughout the time periods of the two years of training. # indicates the testing occasions.

Energetic and Biomechanical data collection

An incremental 7 x 200 m step test (Fernandes et al., 2003) on a long course pool was used to evaluate the swimmer's energetic and biomechanical adaptations. Warm up procedures were standardized before each test. 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. The increments in velocity were chosen, so that swimmers would attain their best performance on the last trial. Underwater pacemaker lights (GBK-Pacer, GBK Electronics, Aveiro, Portugal) on the bottom of the 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. Capillary blood samples were taken from the ear lobe during the 30 s resting period between trials, immediately following and in the 3rd, 5th, and 7th min after of the intermittent protocol. Samples were then analyzed for lactate concentrations (YSI 1500 L, Yellow Springs, Ohio, USA).

The energetical profile was analyzed in terms of aerobic and anaerobic fitness and quantified based on the V_4 (in m s^{-1}) and the La_{peak} (in mmol L^{-1}) assessments. The individual V_4 was obtained by interpolation of the average lactate value (4 mmol l^{-1}) on the exponential curve of lactate/speed relationship. The La_{peak} was considered to be the highest blood lactate concentration in post exercise condition (Termin and Pendergast, 2000).

The biomechanical profile was determined based on the measurement of the SF (in Hz), SL (in m), SI (in m^2.c^{-1}.s^{-1}) and η_p (in %). The SF was recorded manually from three consecutive stroke cycles in the middle of each lap during each trial, using a crono-frequency meter (Golfinho Sports MC 815, Aveiro, Portugal).

Then, SF values were converted to International System Units (i.e. Hz). The SL was estimated as being (Craig et al., 1985):

$$SL = \frac{v}{SF}$$ (1)

where SL is the stroke length (in m), v is the swimming velocity (in m.s^{-1}), and the SF is the stroke frequency (in Hz). The SI is considered as one of the swimming stroke efficiency indexes and was computed as (Costil et al., 1985):

$$SI = v \cdot SL$$ (2)

where SI is the stroke index (in m^2.c^{-1}.s^{-1}), v is the swimming velocity (in m.s^{-1}) and the SL is the stroke length (in m). The η_p was also estimated as being (Zamparo et al., 2005):

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

where v is the swimming velocity (in m.s^{-1}), the SF is the stroke frequency (in Hz) and l is the arm's length (in 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 3 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.

All the energetic and biomechanical values were then estimated @v200 m performance.

Performance data collection

Whenever possible, 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. However, in earlier months of the season most of the competitions take place on short course swimming pools. The most easy and operational way to convert the short course race times in long course race times was to use specific software tool (FINA

converter). This is a common approach used for most of the Swimming National Federations to "convert" race times for national and international meetings. The time between the official competition performances and the testing day never exceeded two weeks.

Statistical analisys

Data was expressed as mean and standard deviation and quartiles for each time period. Within and between season changes in performance, energetic and biomechanical variables were analyzed with Friedman Test, as well as the Wilcoxon Signed-Rank Test. The relative frequency of change (%) for each season was also reported. Ranking Spearman Correlation Coefficient were used to assess the stability between seasons. Qualitatively, stability was considered to be: (i) high if $r_s \geq 0.60$; (ii) moderate if $0.30 \leq r_s < 0.60$ and; (iii) low if $r_s < 0.30$, adapted from Malina (2001). Cohen's Kappa tracking index (k) was obtained in the Longitudinal Data Analysis software (v. 3.2, Dallas, USA) and used to detect inter-individual difference in changes over the season. The qualitative interpretation of k values was made according to Landis and Koch (1977) suggestion, where the stability is: (i) excellent if $k \geq 0.75$; (ii) moderate if $0.40 \leq k < 0.75$ and; (iii) low if $k < 0.40$. Since repeated measures were nested within subjects, the longitudinal data set was treated as hierarchical. A two-level hierarchical linear modelling (HLM) was used to model the performance changes along the two consecutive seasons having selected energetical and biomechanical variables as time change predictors. Maximum likelihood estimation was used with the HLM5 statistical software (Raudenbush et al., 2001), which computes robust standard errors, a convenient option in this study due to small sample size. Also due to small sample size only the fixed effects were considered (Mass and Hox, 2004). The level of statistical significance was set at $P \leq 0.05$.

Results

Changes within and between seasons

Figure 2 presents the changes in energetics, biomechanics and performance. Most of energetic and biomechanical variables presented no significant changes within and between seasons. The only exception was the La_{peak} with a significant increase within the year and from one season to another ($La_{peakTP1} = 9.87 \pm 2.40$ mmol.l^{-1}; $La_{peakTP2} = 11.38 \pm 2.56$ mmol.l^{-1}; $La_{peakTP3} = 13.06 \pm 3.26$ mmol.l^{-1}; $La_{peakTP4} = 10.94 \pm 2.90$ mmol.l^{-1}; $La_{peakTP5} = 12.87 \pm 1.97$ mmol.l^{-1}; $La_{peakTP6} = 12.98 \pm 2.69$ mmol.l^{-1}; p = 0.05). The performance also presented no significant variations.
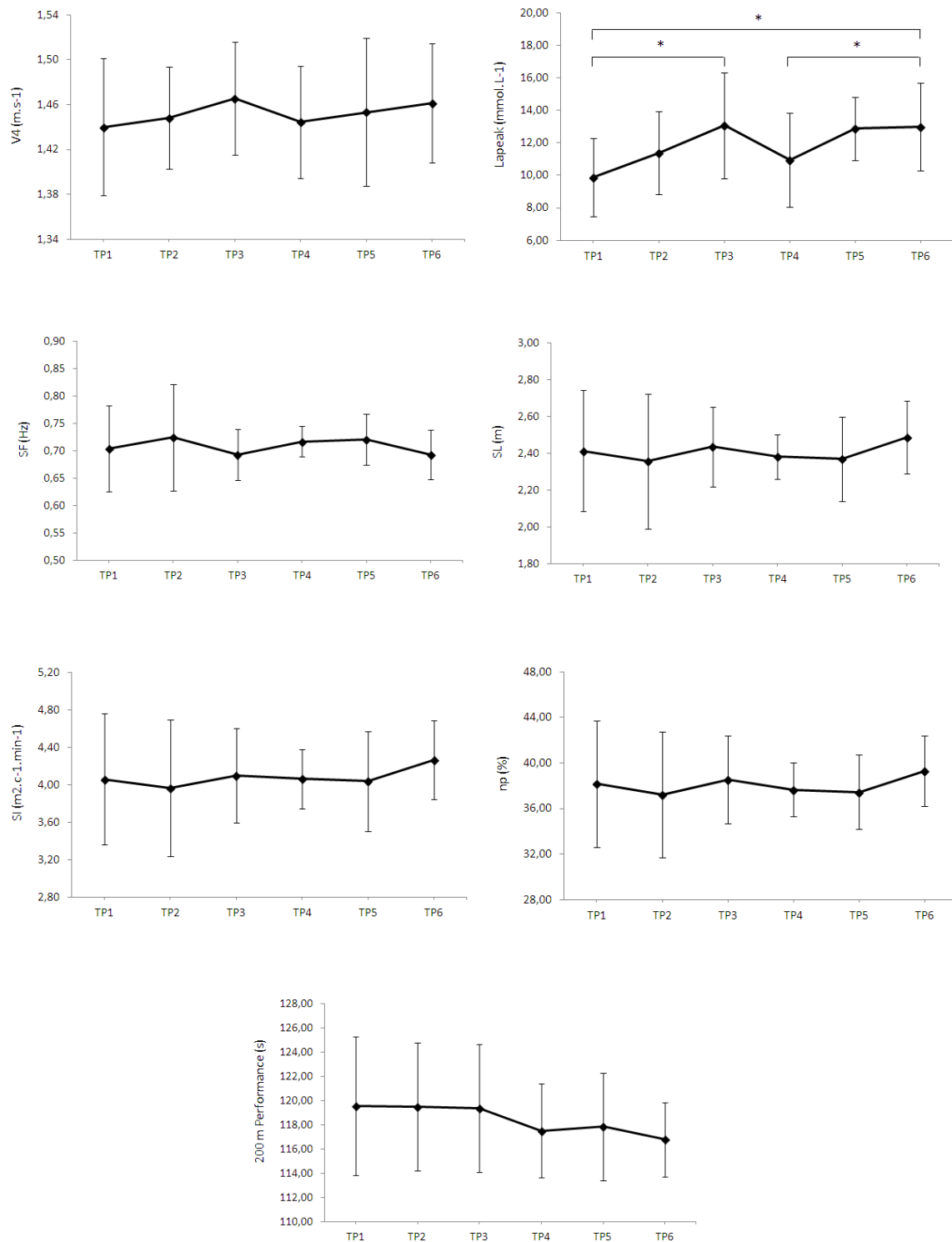
Figure 2. Changes in energetics, biomechanics and performance throughout the two years of training. * indicates significant different from TP_1 to TP_3 (p = 0.02), from TP_4 to TP_6 (p = 0.05) and from TP_1 to TP_6 (p = 0.02).

Table 1 presents the relative changes (%) on energetics, biomechanics and performance throughout the two consecutive seasons. The energetic and biomechanical variables with higher percentage changes were the La_{peak} (1st season = 17.61%; 2nd season = 13.49%) and the SI (1st season = 0.34%; 2nd season = 4.05%), respectively. While for the energetic profile most of the gains were obtained in the first season, in the biomechanical profile the higher range of variation was most notorious in the second one.

Table 1. Relative change (%) on energetics, biomechanics and performance within each year of training.

	2009-2010			2010-2011		
	TP_1-TP_2	TP_2-TP_3	Overall	TP_4-TP_5	TP_5-TP_6	Overall
V_4	0.58	1.12	1.70	0.55	0.54	1.08
La_{peak}	8.97	8.64	17.61	14.41	-0.92	13.49
SF	2.00	-4.83	-2.83	0.14	-4.13	-3.99
SL	-3.26	3.29	0.03	-1.09	4.71	3.61
SI	-3.18	3.52	0.34	-1.44	5.49	4.05
η_p	-3.26	3.29	0.03	-0.97	4.59	3.62
200 m	-0.05	-0.15	-0.20	0.26	-0.86	-0.62

V_4, velocity at 4 mmol of lactate levels; La_{peak}, maximal blood lactate concentration; SF, stroke frequency; SL, stroke length; SI, stroke index; η_p, propelling efficiency; 200 m, freestyle performance time in competition;

Inter-individual variations within and between seasons

Table 2 presents the auto-correlation [Spearman Correlation Coefficients (r_s)] for energetic and biomechanic selected variables. Most of the variables presented high stability ($r_s > 0.60$) throughout the two consecutive seasons. High associations were found in adjacent time periods (e.g. TP_1 vs TP_2) or in similar time periods but from separate seasons (e.g. TP_3 vs TP_6). The k was computed based on three growth curves ("tracks") delimited by the percentiles 33, 66 and 100. The number of times that each swimmer goes out of a specific track reflects the inter-individual stability in a certain characteristic. Low stability was verified for the La_{peak} (k = 0.24 ± 0.12), SF (k = 0.17 ± 0.12), SL (k = 0.30 ± 0.12) and η_p (k = 0.26 ± 0.12). Moderate values were verified for the V_4 (k = 0.42 ± 0.12), SI (k = 0.49 ± 0.12) and 200 m performance (k = 0.60 ± 0.12). This suggests high variability in terms of energetic and biomechanical individual response to training.

Table 2. Interperiod Spearman Correlation Coefficients of energetic and biomechanical variables over the two years of training.

V_4	TP_1	TP_2	TP_3	TP_4	TP_5	TP_6	La_{peak}	TP_1	TP_2	TP_3	TP_4	TP_5	TP_6
TP_1	1						TP_1	1					
TP_2	0.77*	1					TP_2	0.17	1				
TP_3	0.42	0.33	1				TP_3	0.27	0.45	1			
TP_4	0.95**	0.70*	0.46	1			TP_4	0.37	0.30	0.32	1		
TP_5	0.73	0.63	0.64	0.82**	1		TP_5	0.30	0.43	0.92**	0.37	1	
TP_6	0.64	0.73*	0.59	0.60	0.84**	1	TP_6	0.23	0.38	0.47	0.70*	0.48	1
SF	TP_1	TP_2	TP_3	TP_4	TP_5	TP_6	**SL**	TP_1	TP_2	TP_3	TP_4	TP_5	TP_6
TP_1	1						TP_1	1					
TP_2	0.58	1					TP_2	0.64	1				
TP_3	0.75*	0.32	1				TP_3	0.77*	0.58	1			
TP_4	0.20	-0.02	0.44	1			TP_4	0.51	0.58	0.84**	1		
TP_5	0.66	0.74*	0.60	0.25	1		TP_5	0.63	0.83**	0.67*	0.53	1	
TP_6	0.49	0.08	0.61	0.09	0.59	1	TP_6	0.58	0.35	0.80**	0.57	0.67*	1
SI	TP_1	TP_2	TP_3	TP_4	TP_5	TP_6	η_p	TP_1	TP_2	TP_3	TP_4	TP_5	TP_6
TP_1	1						TP_1	1					
TP_2	0.60	1					TP_2	0.60	1				
TP_3	0.73*	0.70*	1				TP_3	0.87**	0.42	1			
TP_4	0.60	0.70*	0.92**	1			TP_4	0.57	0.12	0.80**	1		
TP_5	0.72*	0.87**	0.60	0.58	1		TP_5	0.82**	0.73*	0.65	0.25	1	
TP_6	0.78*	0.60	0.63	0.58	0.87**	1	TP_6	0.77*	0.27	0.78*	0.45	0.72*	1

$p < 0.05$; $p < 0.01$

Hierarchic linear modeling

The first step to model performance in the HLM framework consisted in modeling the changes in performance over the two seasons. In this step only time was include as predictor. The linear, quadratic and cubic changes were tested. Only linear change was significant (Table 3). The second step consisted in testing the energetic and biomechanical variables as swimming performance changing predictors. Both SI and η_p were not included in the analyses since they are composite variables depending on the contributions of SL and SF, respectively. The retained performance predictors from biomechanical domain were the SL and SF, while from the energetic was the V_4. The model shows that the mean of initial swimming performance was 119.28 s and improved linearly 0.35 s between each evaluation. The V_4 had a positive impact in performance, suggesting that for each unity change (in $cm.s^{-1}$) the swimming performance improved 0.11 s. The SL and SF had also a positive impact in performance. For each unity of change in SL (in cm) swimming performance improved 0.36 s, and for each unity of change in SF (in Hz), swimming performance improved 1.21 s.

Table 3. Parameters specification for fixed effects for the two hierarchical linear model with standard errors (SE) and confidence intervals.

Parameter	Estimate (SE)	95% Confidence Interval
First model		
Intercept	119.88 (1.42)	116.74 — 120.01
Time	-0.59 (0.16)	-0.90 — - 0.27
Last model		
Intercept	119.27 (0.37)	118.49 — 120.06
Time	-0.35 (0.09)	-0.53 — - 0.16
V_4	-10.06 (4.69)	-19.57 — -0.55
SL	-36.26 (2.41)	-41.24 — -31.29
SF	-120.97 (8.38)	-137.90 — -104.03

V_4, velocity at 4 mmol of lactate levels; SL, stroke length; SF, stroke frequency;

Discussion

The purpose of this study was to analyze the changes and inter-individual variations in performance, energetic and biomechanical profiles of elite male swimmers throughout two consecutive seasons. Added to that, the most important factors for the performance enhancement during such period were determined. The main result was that no significant changes were observed in performance, energetics and biomechanics within and between seasons. There was a high variability in the swimmer's response to the training periodization. The best energetic predictor of performance was the V_4, while the biomechanical ones were the SL and SF.

Changes within and between seasons

Within and between seasons adaptations were determined for the energetic variables. There was a non-significant increase in V_4 of ~1.7% and ~1.1% in the first and second seasons, respectively. Earlier observations have already reported increases in elite swimmer's V_4 of ~1.5% after several months of training (Pyne et al., 2001; Anderson et al., 2006; Costa et al., 2012). The training induces muscle adaptations and improves the muscle's ability to produce energy aerobically (Madsen, 2003). However, due to several years/decade of systematic and hard training the margin for further aerobic improvement in elite athletes is quite small (Houston et al., 1981). In contrast, the La_{peak} significantly improved. As anaerobic capacity indicator, the increase in La_{peak} revealed an improved anaerobic capacity throughout the season. Training induces muscle anaerobic adaptations allowing higher velocities at an

increased oxygen debt and muscle fatigue (Termin and Pendergast, 2000). The mean percentage of variation was ~18% and ~14% in the first and second years, respectively. Those values are in accordance with previous observations (from ~12% to ~27%) from subjects with similar competitive level (Termin and Pendergast, 2000; Anderson et al., 2006; Faude et al., 2008). The differences in percentage terms may be accounted to the type of training done and also to the duration of the interventions. The high intensity training programs with lower volume promote higher benefits in terms of anaerobic development than long distance ones (Faude et al., 2008). Moreover, four consecutive seasons training at higher intensities (Termin and Pendergast, 2000) seems to induce increases in La_{peak} in a higher range than five weeks (Faude et al., 2008).

For the biomechanical variables, non-significant changes were observed over the two consecutive years. The SF decreased ~3% and ~4% within the first and second seasons, respectively. Conversely, the SL increased ~0.1% and ~4% throughout those time periods. Similar magnitude of change has already been determined for international and national male swimmers within one single season (Costa et al., 2012). This SF and SL relationship throughout several months seems to depend on the training characteristics. The high volume training programs have been found to increase SL but not the SF (Costill et al., 1991; Wakayoshi et al., 1993; Costa et a., 2012). While swimming at lower speeds, subjects can focus on stroke phase aspects, and therefore increase the distance swum per stroke. However, such programs do not seem develop so easily the muscular power and strength (Dudley and Fleck, 1987). At some point of their carriers, elite swimmers obtain a maximal technical ability, turning out to be difficult (but not completely impossible) to observe substantial changes in the stroke mechanics. Further adaptations are only accomplished with new intensity approaches. Indeed, an increase in training intensity in the second season was determinant to change SF and SL in a higher range than in the first one. In overall perspective, the kinematical combination demonstrated by the present subjects is in accordance with the strategy adopted by elite swimmers that made them more efficient than lower level ones (Costa et al., 2012). An increase in swimming stroke efficiency throughout the study was demonstrated by both indexes. The SI and η_p increased ~4% and 3% during the two years of training, respectively. The SI depends on the velocity and SL adaptations (Costill et la., 1985). A higher SI over the season represented an improved ability to swim at similar velocities traveling higher distances within a stroke cycle. On the other hand, the η_p is determined by the relationship between velocity and SF (Zamparo et al., 2005). Seasonal adaptations allowed the swimmers to reach similar velocities with fewer strokes. Previous studies have also reported efficiency increases in

international and national level swimmers during one single season (Costa et al., 2012). However, the variation in both indexes (2 to 3%) was lower than in the present study. It seems that the duration of the intervention is a major factor influencing the magnitude of change.

The swimmers became faster within and between seasons. Despite there was no significant differences, their race times slightly improved -0.20% and -0.60% on average in the first and second seasons, respectively. A lack of improvement, or a small magnitude of it, has been published in a couple of other papers as well (Costill et al., 1991; Pyne et al., 2001; Costa et al., 2012). Elite swimmers have some difficulties in promote meaningful improvements in a single season. Indeed, high stabilization in freestyle race times seems to start more or less at 16 years old (Costa et al., 2011). From that point on, any attempt to induce further improvements may require a new type of training. Every little gain obtained has trivial importance to be well placed or even reach medals in important competitions. Mujika et al. (1995) reported that improvement in performance of elite swimmers was significantly correlated (r = 0.69) with the mean intensity of the training season, but not with training volume or frequency. In the present study, the volume and frequency remained slightly unaltered from one season to another. However, an increase in training intensity during the second season was effective to enhance performance in a large rate (0.40%) than in first one. In this sense, coaches should mostly manipulate intensity rather than volume or frequency in their periodization training programs to improve performance. Since the variation on energetic and biomechanical factors in this kind of athletes is remarkably small, there is a need to conduct larger longitudinal interventions to obtain significant results.

Inter-individual variations within and between seasons

The longitudinal assessment based on auto-correlation coefficients showed high stability during both seasons. This confirms that monitoring the factors affecting performance in elite athletes presents an extra-challenge (Davidson et al., 2009). Elite swimmers have reached a pre-determined genetic limit. Any attempt to impose significant adaptations lead to quite small changes. Such as in adherence to physical activity (Malina, 2001), it seems that the auto-correlations values tend to increase after adolescence when evaluating elite subjects. High associations were even most notorious in adjacent time periods or in similar time periods but from different seasons. It means that the status of the energetic and biomechanical variables is very similar between the first and the second seasons. This may happen because the adaptations within the year are cyclical in nature (Pyne et al., 2001; Anderson et al., 2006). It is expected that some capacities will be lost (i.e. detraining phenomena) in off-season. Thus,

coaches should advise their swimmers to remain active in off-season, in order to maintain their fitness at somewhat higher levels, and to avoid the lost of "water sensitivity" and their basic technique efficiency. Nevertheless, when increasing the time frame analysis, the stability might decrease. A couple of papers presented a moderate (Costa et al., 2010) and low (Costa et al., 2011) stability for elite swimmers competitive performance during five and seven year's time period, respectively.

The k values demonstrate the ability of each swimmer to remaining on a specific curve of growth (called "track") and it reflects stability within that standard. It is possible to observe in a more accurate way the change of individual curve along with the inter-individual differences. For most of variables analyzed, the k presented low-moderate stability. This represents high variability in the individual response to training. Swimmers demonstrated the ability to change of track within and between seasons, suggesting that individually they used the most freely chosen energetic and biomechanical combination over the season to maintain the performance at higher levels. Earlier observations have determined similar trend when analyzing the energetic and biomechanical status of elite swimmers in a longitudinal perspective (Anderson et al., 2006). In this sense, it seems that diagnosis and prescription on elite athletes should be focused on individual assessments based on the subjects' intrinsic characteristics rather than in the assumption that "one size fits all".

Hierarchic linear modeling

The HLM demonstrated the V_4 was the best energetic predictor of performance. It is known that swimming efforts lasting less than three minutes require the contribution from both aerobic and anaerobic systems (Troup, 1991). Regarding the 200 m freestyle race, recent findings observed a substantial contribution (~66%) from the aerobic pathway (Figueiredo et al., 2011). It seems that an increased aerobic capacity within and between seasons, indicated by an increased V_4, was the major energetic adaptation for the performance enhancement. For each unity of change in V_4 (one $cm.s^{-1}$), the performances of these swimmers improved 0.11 s. Positive effects were also evident for biomechanical variables, namely the SL and SF. For each unity of change in SL (one cm) swimming performance improved 0.36 s. Improvements in 200 m freestyle competition performance within one single season were due to increases in SL (Costa et al., 2011a). At similar velocities, the ability to travel higher distances within a stroke cycle, represents the need to perform less strokes and therefore less energy demand in the race (Barbosa et al., 2008). However, at the top of their careers, elite swimmers reach a maximal technical ability. Added to that, anthropometric changes are reduced after

adolescence. Increases in swimming velocity can be accomplished by different combination between SL and SF (Craig et al., 1985). Indeed, as demonstrated by the k values, there was high variability in the swimmers kinematical adaptations during the two consecutive seasons. Those who are not able to reach higher velocities based on SL probably used the manipulation of SF for such purpose. The HLM showed a positive impact of SF on performance. For each unity of change in SF (Hz) performance improved 1.21 s. This kind of kinematical strategy was already demonstrated by elite swimmers, and showed to have benefits on short distance freestyle performance from one year to another (Termin and Pendergast, 2000; Huot-Marchand et al., 2005). In this sense, the manipulation of energetic (V_4) and biomechanical (SF and SL) factors according to individual characteristics, are determinant aspects to induce further improvements on 200 m freestyle performance of elite swimmers.

One problem often found in training studies is the need to use convenience samples, which in the most of the cases comprises few athletes. Nevertheless, the number of swimmers that completed the present study is in accordance with earlier longitudinal designs (Sharp et al., 1984; Wakayoshi et al., 1993; Pyne et al., 2001; Faude et al., 2008; Costa et al., 2012). Generally, the energetic characterization during cross sectional studies comprises the assessment of other variables not selected for this research (e.g. oxygen uptake, total energy expenditure, energy cost). Such variables are not assessed on regular basis during longitudinal interventions due to logistic issues related to such experimental set-ups (i.e, very time consuming, increase the number of human resources needed for data collection, etc). On top of that, we have identified some practical factors that can be used as diagnostic tools to induce improvements on competition performance within and between seasons.

In summary, this study demonstrates that elite male swimmers have some difficulties in induce substantial changes on their performance, energetic and biomechanical profiles within and between seasons. Each swimmer has a singular way responding to the training load applied. Improvements on performance can be accomplished by manipulating the V_4, SF and SL.

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Chapter 5

Effects of swim training on energetics and performance

Abstract

The aim of this study was to determine the effect of several months of training on performance and energetic profile of elite swimmers. Nine elite swimmers were evaluated on three different time periods during the 2010-2011 season. Swimming performance was assessed based on time's lists of 200 m freestyle event. An incremental set of 7 x 200 m swims was applied to obtain the energetic data. Measurements and/or estimations were made for the: velocity at 4 mmol l^{-1} of lactate concentrations, highest value of lactate concentrations, maximal oxygen consumption, minimum swimming velocity where the maximal oxygen consumption is reached and total energy expenditure (E_{tot}). The performance and most of the energetic variables assessed presented no significant variations during the study period. The only exception was the E_{tot} with significant differences between all measurements. Correlation coefficients suggested a high stability for all variables. Cohen's Kappa tracking index demonstrated high variability in the individual adaptations to training. It is concluded that elite swimmer's demonstrate a slight improvement in performance and energetic profile in response to several months of training. Each subject has a singular way in adapting to the training load, combining the different energetic confounders to enhance performance.

Introduction

The evaluation of seasonal performance and energetic adaptations in cyclic and closed sports are critical elements of testing for the coach and athlete. The ability to monitor changes within a season provides fundamental information on the response of swimmers to their training periodization. Since performance depends from energetic profile (Barbosa et al., 2010a), there are some variables that can provide, in a simplified point of view, an important feedback on training progress and in competition conditions (Anderson et al., 2006). Among those variables are the velocity at 4 mmol of blood lactate concentrations (V_4), the highest value of lactate concentration (La_{peak}) and the maximal oxygen consumption (VO_2max). Earlier observations reported that there is a trend for elite swimmer's V4 improvement throughout the season (Sharp et al., 1984; Ryan et al., 1990; Costill et al., 1991; Pyne et al., 2001; Anderson et al., 2006). The highest degree of change occurred during the months where an increase in training volume was evident (Sharp et al., 1984; Ryan et al., 1990). Increases in the La_{peak} seem to be consistent throughout a training season as well (Termin and Pendergast, 2000; Bonifazi et al., 2000; Anderson et al., 2006; Faude et al., 2008). However, in this case, the adaptations appear to occur from mid phases of the season until its end (Faude et al., 2008). The VO_2max of elite swimmers seems to remain unchanged during such period (Houston et al., 1981; Costill et al., 1991). Despite the absence of improvement reported for this cohort, significant adaptations were already observed for less skilled swimmers (Magel et al., 1975).

Generally, the annual training plan is divided into smaller and more manageable parts to ensure correct peaking for the main competitions within the year. Contents such as volume, intensity and frequency are among the factors described by coaches in their periodization design (Mujika, 1998). Indeed, to ensure progressive and optimal adaptations, the combination of those aspects is in a constant change throughout large part of the season. Most of the earlier longitudinal interventions conducted on this topic were exclusively based on high volume training programs. Such studies rarely presented a meaningful variation in the training intensity applied. Simultaneously, the evidences about the energetic variations of national/international level subjects throughout larger training periods remain scarce.

Another important aspect of training diagnosis is the individual response to periodization. The assessment of individual trends on performance and energetic measures facilitates the adequate prescription for further adaptations. To the best of our knowledge one single study has examined the elite individual responses throughout a considerable period of training.

Anderson et al. (2006) observed high variability between sex and competitive level in energetic responses throughout six consecutive seasons of training.

Therefore, the present study aimed to determine the effect of several months of training on performance and energetic profile of elite swimmers. In addition, we tried to verify, within and between swimmers, the adaptations variability to training periodization. It was hypothesized high stability for performance and energetic variables during the training period along with high variability between swimmers adaptations to the same training load.

Methods

Subjects

Eleven simmers were recruited to participate in the present study. Two swimmers were excluded because an acute injury (n = 1) and sports withdrawal (n = 1). A total of nine male swimmers (21.0 ± 3.30 years old; 1.80 ± 0.06 m of height; 74.49 ± 6.74 kg of body mass; 23.06 ± 1.94 kg m^{-2} of body mass index; 1.86 ± 0.07 m of arm span; 115.03 ± 3.97 s of personal record in the 200 m long course freestyle event) were considered for further analysis. Four subjects had regular presence in international meetings representing the National Swimming Team, whereas the remaining five swimmers were Top-20 nationally ranked in the 200 m freestyle distance. All the swimmers had as main competitive goal of the season to enhance the 200 m freestyle performance on individual and/or relay events. All subjects gave their written informed consent before participation. The procedures were performed in accordance with the ethical standards proposed by Harris and Atkinson (2009).

Study Design

The swimmers were studied in three occasions during the 2010-2011 calendar. The three tests were conducted at the end of the following time periods: (i) October-December 2010 (TP$_1$); (ii) January-March 2011(TP$_2$) and; (iii) April-June 2011(TP$_3$). Those were pre-taper periods (i.e., where the swimmers were not tapering for the major competition). In the time period before tests the swimmers completed a full training preparation. Weekly volume averaged 44 ± 7 km wk^{-1} (Figure 1). Swim training applied before each evaluation point generally consisted in nine sessions per week involving low, medium and high aerobic tasks, intense sprint work and technical drills. There was an intensity variation throughout the season namely in: (i) intensity corresponding to their aerobic capacity (TP$_1$: 1.88 ± 1.68 km wk^{-1}; TP$_2$: 3.08 ± 2.01 km wk^{-1}; TP$_3$: 3.24 ± 2.32 km wk^{-1}); (ii) intensity corresponding to their aerobic power (TP$_1$: 1.50 ± 0.49 km

wk^{-1}; TP$_2$: 1.68 ± 1.05 km wk^{-1}; TP$_3$: 1.78 ± 0.76 km wk^{-1}) and; (iii) anaerobic capacity training (TP$_1$: 1.04 ± 0.63 km wk^{-1}; TP$_2$: 1.30 ± 0.54 km wk^{-1}; TP$_3$: 1.52 ± 0.21 km wk^{-1}).

In the day prior to data collection, the swimmers completed a low intensity training session in order to avoid data bias due to fatigue. On the testing day, the swimmers performed an intermittent set of 7 x 200 m front crawl, with increasing velocity as described elsewhere (Fernandes et al., 2003). This intermittent protocol was already been shown to be a valid and reliable method for the VO$_2$max assessment (Fernandes et al., 2003). The velocities increased by 0.05 m s^{-1} so that swimmers would attain their best performance on the last trial. Underwater pacemaker 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. A 30 s resting period was used between trials to collect blood samples and oxygen uptake measurements for further energetic analysis.
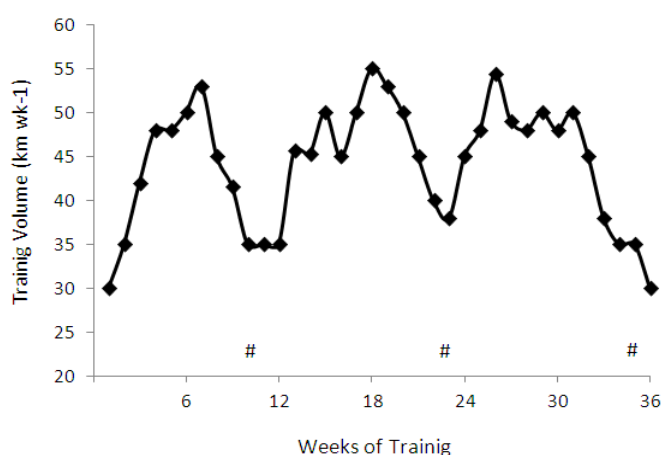

Figure 1. Total weekly volume throughout the competitive season. # indicates the testing occasions.

Performance Data Collection

Whenever possible, 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. However, in earlier months of the season most of the competitions take place on short course swimming pools. The most easy and operational way to convert the short course race times in long course race times was to use specific software tool (FINA converter). This is a common approach used for most of the Swimming National Federations to "convert" race times for national and international meetings. The time between the official competition performances and the testing day never exceeded two weeks.

Energetics Data Collection

To determine the V_4 and La_{peak}, capillary blood samples were collected from the ear lobe to obtain the lactate concentrations with an auto-analyzer (YSI 1500 l, Yellow Springs, Ohio, USA). Collecting process occurred during the 30 s resting period between trials, immediately following and in the 3rd, 5th, and 7th min after the intermittent protocol. The individual V4 (m s^{-1}) was obtained by interpolating the average lactate value (4 mmol l^{-1}), with the exponential curve of lactate/velocity. The La_{peak} (mmol l^{-1}) was considered to be the highest blood lactate concentration in post exercise condition (Termin and Pendergast, 2000).

Oxygen uptake was measured immediately after each trial with a portable gas analyzer (Cortex, Model MetaLyzer 3B, Leipzig, Germany). Swimmers were instructed to take their last breathing cycle before touching the wall. After finishing the trial, the swimmer leaned on the wall, while an operator fixed a portable mask for land-based locomotion on his face during all recovery. None breathing cycle was made until the portable mask was in the swimmer's face. The time gap for this transition and the first gas exchange never exceeded the 3 s. The VO_2 (ml kg^{-1} min^{-1}) reached during each step of the protocol was estimated using the backward extrapolation of the O_2 recovery curve (Laffite et al., 2004). The VO_2max was considered to be the mean value in the 6 seconds after the VO_2 detection during the recovery period (Laffite et al., 2004). The first measure of VO_2 values before the highest VO_2 measurement was not considered, which corresponded to the device adaptation to the sudden change of respiratory cycles and of O_2 uptake. The device adaptation never exceeded 2 seconds. Other backward extrapolation methods were already been reported (Leger et al., 1980; Montpetit et al., 1981) and have been shown valid for the VO_2max measurement. The vVO_2max (m s^{-1}) was considered to be the swimming velocity corresponding to the first stage that elicited the VO_2max (Fernandes et al., 2006a).

The total energy expenditure (E_{tot}) can be described on its metabolic elements in terms of aerobic and anaerobic contributions (Zamparo et al., 2010). In the present study, the E_{tot} (kJ) was calculated in the last 200 m trial of the incremental test, corresponding to the swimmer's maximal effort. Due to logistic and training reasons, while conducting longitudinal designs the methods applied should be easy to operate. Despite the La_{peak} values of the incremental test being in accordance with those reported earlier for an all out effort (Termin and Pendergast, 2000), these findings should be interpreted carefully. The blood lactate increases in the first stages of the incremental test may have influence in the post exercise lactate value and as a consequence overestimate E_{tot}. Thus, E_{tot} was obtaining according with the equation:

$$E_{tot} = Aer + AnS \qquad (1)$$

where Aer represents the aerobic contribution (kJ) based on the total oxygen volume and AnS represents the anaerobic contribution (kJ) based on the blood lactate variation.

The total oxygen volume (l) consumed during the last trial was estimated from the following equation:

$$VO_2 = VO_2net \cdot t \cdot M \qquad (2)$$

where VO_2net (l kg^{-1} min^{-1}) is the difference between the oxygen uptake measured and the oxygen at rest, t (min) is the total duration of the effort and M (kg) is the mass of the subject. Aerobic contribution was then expressed in kJ assuming an energy equivalent of 20.9 kJ l O_2^{-1} (Zamparo et al., 2010).

The O_2 equivalent (ml O_2) for the lactate variation was obtained according the equation:

$$O_2Eq = La_{net} \cdot 2.7 \cdot M \qquad (3)$$

where La_{net} represents the difference between the lactate measured and the lactate at rest, 2.7 is the energy equivalent (ml O_2 $mmol^{-1}$ kg^{-1}) for lactate accumulation in blood (di Prampero et al., 1978) and M (kg) is the body mass of the swimmer. Thus, the anaerobic contribution (ml O_2) was expressed in kJ assuming an energy equivalent of 20.9 kJ l O_2^{-1} (Zamparo et al., 2010).

Statistical Procedures

All assumptions to conduct the ANOVA (normality, independency and homoscedasticity) were checked-out. Since the assumptions failed, non-parametric procedures were adopted. Longitudinal assessment was made based on two approaches: (i) mean stability and; (ii) 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, and also the Wilcoxon Signed-Rank Test to assess differences between time periods. Normative stability was analyzed with the Ranking Spearman Correlation Coefficient. Qualitatively, stability was considered to be: (i) high if $r \geq 0.60$; (ii) moderate if $0.30 < r < 0.60$ and; (iii) low if $r < 0.30$, adapted from Malina (2001). The Cohen's Kappa (k) plus one standard deviation, with a

confidence interval of 95 % (Costa et al., 2012) was also computed as another normative stability parameter to detect inter-individual differences. The qualitative interpretation of k values was made according to Landis and Koch (1977) suggestion, where the stability is: (i) excellent if k > 0.75; (ii) moderate if 0.40 < k < 0.75 and; (iii) low if k < 0.40. 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 2 presents the 200 m freestyle performance variation during the three consecutive time periods. No significant variations were verified for this variable throughout the season (200 m perfomance$_{TP1}$ = 117.58 ± 3.94 s; 200 m performance$_{TP2}$ = 117.75 ± 4.37 s; 200 m performance$_{TP3}$ = 117.22 ± 3.54 s; p = 0.90). Wilcoxon ranking tests also demonstrated no significant differences between pair wised time periods.
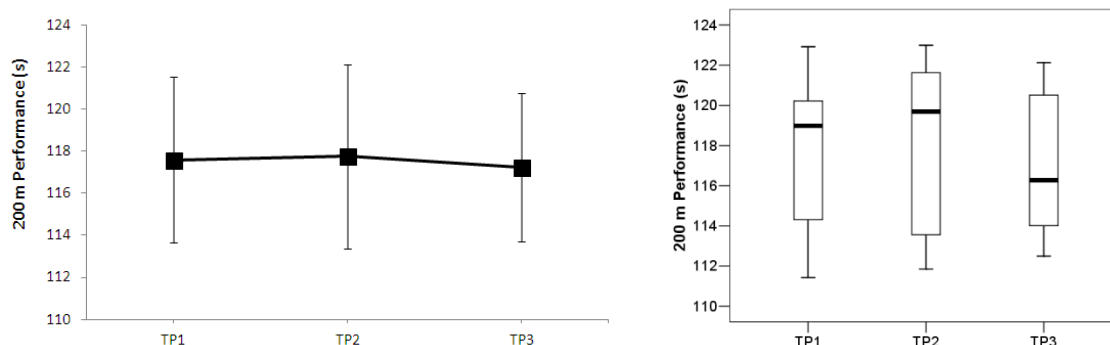

Figure 2. Variation of the 200 m freestyle performance throughout the competitive season.

Figure 3 demonstrates the energetic profile variation throughout the competitive season. Most of variables presented no significant variations (V$_{4TP1}$ = 1.44 ± 0.05 m s^{-1}; V$_{4TP2}$ = 1.45 ± 0.06 m s^{-1}; V$_{4TP3}$ = 1.45 ± 0.05 m s^{-1}; p = 0.56; La$_{peakTP1}$ = 11.37 ± 2.66 mmol l^{-1}; La$_{peakTP2}$ = 12.77 ± 2.08 mmol l^{-1}; La$_{peakTP3}$ = 12.88 ± 2.78 mmol l^{-1}; p = 0.72; VO$_2$max$_{TP1}$ = 71.91 ± 11.60 ml kg^{-1} min^{-1}; VO$_2$max$_{TP2}$ = 73.61 ± 8.23 ml kg^{-1} min^{-1}; VO$_2$max$_{TP3}$ = 76.35 ± 6.12 ml kg^{-1} min^{-1}; p = 0.24; vVO$_2$max$_{TP1}$ = 1.56 ± 0.04 m s^{-1}; vVO$_2$max$_{TP2}$ = 1.56 ± 0.07 m s^{-1}; vVO$_2$max$_{TP3}$ = 1.57 ± 0.05 m s^{-1}; p = 0.17). The only exception was the E$_{tot}$ with a significant increase during such period (E$_{totTP1}$ = 234.71 ± 22.53 kJ; E$_{totTP2}$ = 242.96 ± 24.88 kJ; E$_{totTP3}$ = 262.86 ± 22.48 kJ; p = 0.01).
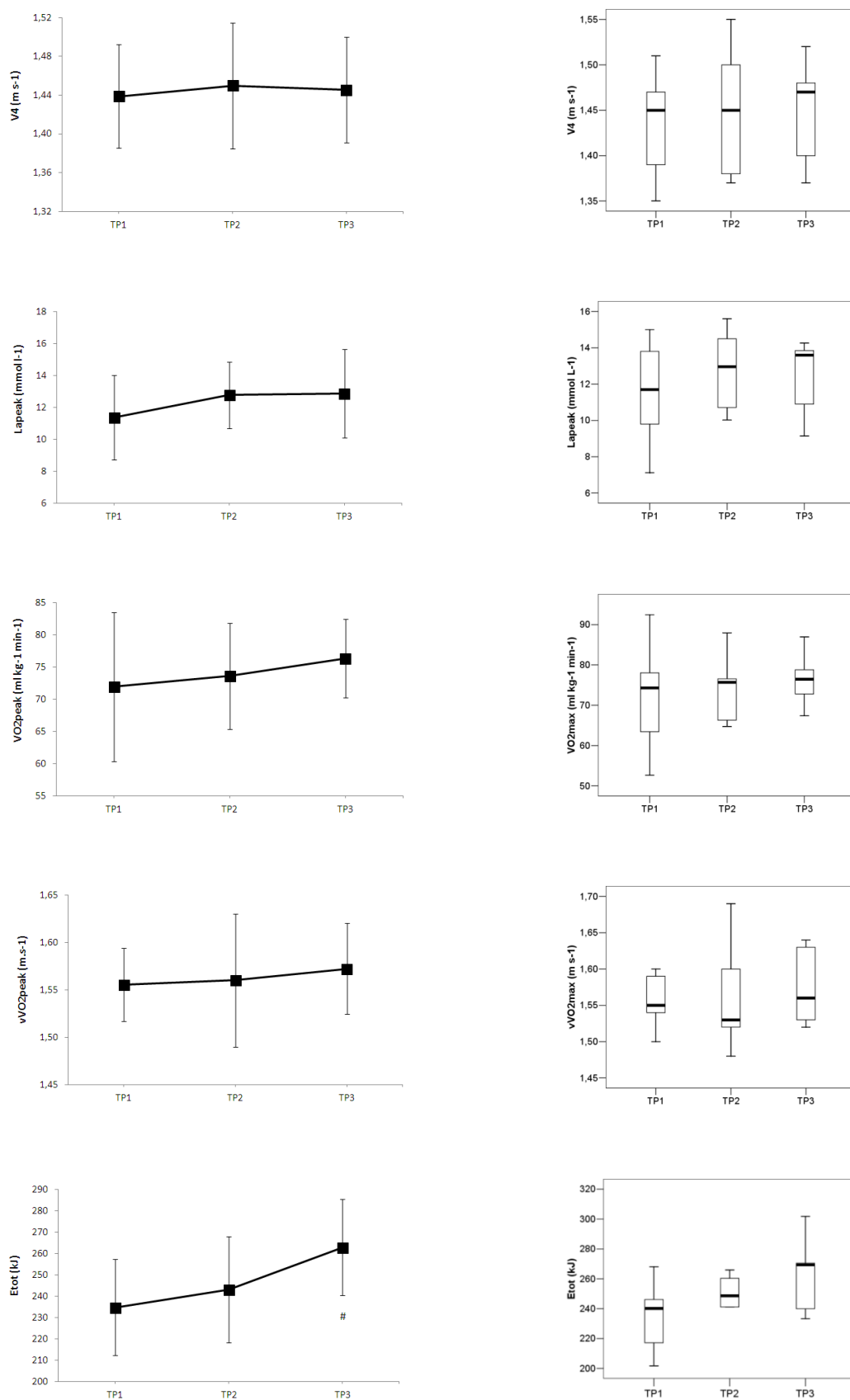
Figure 3. Variation of energetic variables throughout the competitive season. # indicates significant different from TP_1 and TP_2.

Table 1 presents the Spearman Correlation Coefficient values for pair wised time periods throughout the season. Associations were significant between variables in almost paired data. Most variables presented high stability ($r_s > 0.60$) during such period.

Table 1. Interperiod Spearman Correlation Coefficients of performance and energetic variables measured 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)	0.93**	0.88**	0.92**
V_4 (m s^{-1})	0.81**	0.78*	0.79*
La_{peak} (mmol L^{-1})	0.22	0.60	0.53
VO_2max (ml kg^{-1} min^{-1})	0.88**	0.70*	0.63
vVO_2max (m s^{-1})	0.79*	0.80**	0.84**
E_{tot} (kJ)	0.42	0.68*	0.50

* $p < 0.05$; ** $p < 0.01$

The k values for a 95% confidence interval were rather low for the La_{peak} (k = 0.17 ± 0.27) and E_{tot} (k = 0.39 ± 0.27). Moderate values were verified for the V4 (k = 0.44 ± 0.27), VO_2max (k = 0.44 ± 0.27) and vVO_2max (k = 0.44 ± 0.27). Only in the 200 m freestyle performance swimmers demonstrated a high inter-individual stability (k = 0.78 ± 0.27).

Discussion

The aim of this study was to determine the effect of several months of training on performance and energetic profile of elite swimmers. The main result was that no significant variations for energetic profile and performance were observed. Most variables assessed presented high stability values. In addition, each swimmer demonstrated a singular way in responding to training over the season.

In the present study the 200 m freestyle performance slightly improved (~0.36 s). In percentage terms, the mean variation in performance time was -0.32 ± 1.56 %. This magnitude of change was similar to that reported in earlier observations (Pyne et al., 2001; Costa et al., 2012) in subjects from similar competitive level (-0.30 %). Due to maturational and physiological reasons, elite swimmers start to demonstrate a lack of meaningful improvement in freestyle performance starting at the age of 16 years (Costa et al., 2011). From this moment forward, the relative changes in performance are not so obvious. From a statistical point of view it becomes very difficult to verify significant differences in race times from one year to another. Any attempt to induce significant improvements may require a new specific type of

training or a longer period to be expressed. The performance depends mainly from training intensity and less from volume or frequency (Mujika et al., 1995). Swimmers submitted to a high intensity training program demonstrated a percentage of improvement in the 200 yard event of 1.9, 3.1, 2 and 1.3 % over four consecutive seasons, respectively (Termin and Pendergast, 2000). In this sense, coaches need to rethink the type of training that should be proposed to this kind of swimmers to impose significant performance enhancements.

Tracking the factors affecting performance in elite population presents an extra-challenge (Davidson et al., 2009). Several papers determined an absence and/or a slight improvement in the energetic variables after several longitudinal assessments (Houston et al., 1981; Costil et al., 1991; Pyne et al., 2001; Anderson et al., 2006; Costa et al., 2012). This might be explained by the great energetic status of elite athletes at the career peak due to several years/decade of systematic and hard training. They have reached, or are getting closest to their predetermined genetic limit, and any margin for further adaptations is quite small (Houston et al., 1981). Most of energetic variables assessed do not changed significantly throughout the course of the study. However, from a general point of view, slight changes were observed for each one.

The V_4 is described as an aerobic capacity indicator (Ribeiro et al., 1990). Aerobic capacity presents strong association with high intensity exercises lasting about 2 min such as the 200 m freestyle performance (Gastin, 2001). Usually, the highest degree of change in the aerobic capacity happens in the first months where an increase in the training volume is evident (Sharp et al., 1984; Ryan et al., 1990). In that stage of the season, the muscle is more sensitive to adaptations becoming more effective in producing energy aerobically (Madsen, 1983). However, when the personal aerobic peak is reached, not even additional increases in volume will promote significant changes (Ryan et al., 1990). The V_4 increased from TP_1 to TP_2 and remained stable until TP_3. Probably the personal peak of the swimmers was reached somewhere between the TP_2 suggesting an inability to increase the V_4 from that point on.

The VO_2max and vVO_2max are considered important variables for constant intensities above the aerobic capacity. Such parameters are commonly used to express the aerobic power in the 200 m efforts (Fernandes et al., 2006a; 2008; Sousa et al., 2011). The VO_2max showed a non-significant increase throughout the season. The capacity both to transport and utilize oxygen increased as the result of training. However, it was not sufficient to be improved in a statistical point of view. Similar trend was already reported for elite university swimmers (Houston et al., 1981). Despite the absence of pronounced improvement reported for this kind of subjects, distance training resulted in significant adaptations in less skilled ones (Magel et al., 1975). As previously suggested, the much time spent in high distance training at lower intensities does

not provide the sufficient and/or the appropriate stimulus to improve VO_2max in elite swimmers (Houston et al., 1981; Termin and Pendergast, 2000).

No research was until now conducted regarding the vVO_2max status in a longitudinal perspective. The vVO_2max showed a non-significant increase throughout the season. The more time spent on training at the intensity corresponding to their aerobic power from TP_2 to TP_3 was able to bring slight benefits in vVO_2max. The swimmers were able to deliver their amount of energy more effectively at higher velocities than in the earlier months of training. Indeed, as demonstrated in figure 2, both performance and vVO_2max show similar trend in adaptations throughout the season. Cross-sectional evidences have already demonstrated strong correlations between vVO_2max and efforts requiring prolonged aerobic power such as the 200 m freestyle distance (Fernandes et al., 2003), although data suggested that swimmers presenting higher vVO_{2max} showed lower capacity to sustain an intensity corresponding to this velocity (vVO_2max) (Fernandes et al., 2006b). This can suggest that vVO_2max can be a useful tool for coaches to understand their swimmer's 200 m freestyle performance throughout the season.

The La_{peak} is related with sprinting performance and was already used to assess the maximal anaerobic capacity in 200 m distances (Avlonitou, 1996). With training the muscle suffers some adaptations that allow reaching higher velocities at an increased oxygen debt and reduced muscle fatigue (Termin and Pendergast, 2000). Male swimmers developed their seasonal anaerobic qualities as indicated by the increase in La_{peak} (Anderson et al., 2006). Similar trend was observed in the present study, where an increase in the anaerobic training was effective to promote a slight increase in the La_{peak}.

The E_{tot} expresses the total energy expenditure for a given event (Barbosa et al., 2005; 2006). A significant increase was determined for this variable over the season. E_{tot} can be described on its metabolic elements in terms of aerobic and anaerobic contributions (Zamparo et al., 2010). Large part of the training is made to improve those different energy production systems (Toussaint and Hollander, 1994). The slight increases in VO_2max indicated a higher ability to produce energy by the aerobic source. Simultaneously, the seasonal development in the anaerobic qualities was achieved by a non-significant change on La_{peak}. Thus, the non-meaningful increases in the VO_2max and La_{peak} may have leaded to a significant change in E_{tot} over the season. The E_{tot} is influenced by several factors, and it is not possible to fully understand swimming performance without an integrated/holistic perspective of both (at least) physiologic and biomechanical domains. The E_{tot} increases exponentially with an increase in swimming velocity due to an increase in drag force (di Prampero et al., 1978). Consequently,

elite swimmers training should improve the ability to apply power to propulsion in an efficient manner to decrease the E_{tot} at higher velocities. In this study it was verified that swimming velocity slightly improved, but the E_{tot} increased significantly. Although training have promoted a compensatory propulsive gain to slightly improve performance, that additional energy was not used in a efficient manner. Probably, that energy spent per unit of distance increased and, consequently, or the gross efficiency decreased, or the drag force increased. There is a trend throughout the season for male swimmers became stronger (i.e. increase body volume). At least one study determined such phenomena in male swimmers from this competitive level throughout several years of training (Anderson et al., 2006). This aspect will impose a higher trunk and limbs area suggesting an increased energy spent to overcome higher drag forces. The more economic swimmer is not necessarily the faster one. For one swimmer to become faster with lower economy significant gains in other performance determinants are required. It is possible that an improved technical skill throughout the season imposed an increase in the gross efficiency and allowed to slightly enhance performance. Nevertheless, those are biomechanical factors that were not considered for analysis, and therefore a conclusion cannot be drawn. Further research should include those mechanical elements to understand their behavior in a longitudinal perspective.

The longitudinal assessment based on auto-correlation coefficients showed high stability for the performance and for the majority of the variables assessed. Malina (2001) demonstrated that the inter-correlations values tend to increase after adolescence. This confirms earlier observations that reported a stable energetic profile (Costa et al., 2012) and a greater consistency in competitive performance (Trewin et al., 2004; Costa et al., 2012) in elite adult swimmers.

The tracking based on k values was computed as another normative stability parameter. Computing the k we can observe the trend of a subject in remaining on a specific curve of growth (called "track") and if it reflects stability within that standard. It is possible to obtain in a more accurate way the relevant aspects of performance kinetics, and to verify the change of individual curve along with the inter-individual differences. For the energetic variables assessed, the k values demonstrated low-moderate stability. This suggests that, in the main curve pattern that all swimmers share it, based on what is considered as the "energetic growth", several individual changes are verified expressing their own adaptations. Each swimmer used the most freely chosen energetic combination (e.g an increased aerobic capacity and lower anaerobic one; or vice versa) to maintain the performance at higher levels

throughout the season. High variability in some energetical aspects was observed in elite swimmers over five consecutive seasons (Anderson et al., 2006).

Methodological issues

The study allows tracking the energetic and performance progression through only one part of the season instead a full-season. For a full-season investigation, it should be added a baseline and a post-tapering evaluation moment. In this investigation, the swimmers were monitored for at least 10 months. Data shows that some practical variables were stable enough to be used as diagnostic tools for further adaptations in performance and energetic profile during the remaining season.

One problem often found in training studies is the need to use convenience samples. In most cases, such interventions comprise a reduce sample size. Nevertheless, the sample size of this investigation is in accordance with earlier longitudinal designs (Houston et al., 1981; Sharp et al., 1984; Wakayoshi et al., 1993; Pyne et al., 2001; Faude et al., 2008; Costa et al., 2012.

Presently, most of the recent studies in aquatic environment used portable apparatus connected to swimming snorkels for the gas exchange measurement. Indeed, manufacture described this snorkels as being light, hydrodynamic, ergonomic and comfortable, with waterproof design, high accuracy and reliability. However several constrictions were already determined while swimming front crawl with such apparatus (Barbosa et al., 2010b). The main changes in swimming velocity imposed by its use do not occur in the main stroke cycle variables while swimming but in other race phases (i.e. gliding phase and turns).

Longitudinal designs require more operative experimental procedures that are easy to apply (i.e. less time-consuming and with a minimal effect on the daily/weekly/monthly training program) than the ones for cross-sectional studies. To avoid such limitations we used the backward extrapolation method, which was already reported in previous studies (Leger et al., 1980; Montpetit et al., 1981; Laffite et al., 2004). The backward extrapolation method showed an acceptable accuracy ($r = 0.88$) to estimate VO_2max (Montpetit et al., 1981). Furthermore, it allows the swimmer to perform each bout in a much more mimetic manner than during training and competition. However, several limitations are associated to this procedure such as: (i) the inability to obtain the oxygen uptake kinetics during exercise and; (ii) it is not a direct measure but an estimation of the gas exchange collection imposing some slight bias.

Conclusions

In conclusion, there seems to exist high stability in most selected energetic variables during large part of the season. Elite swimmers did not present significant adaptations in the performance and energetic variables after several months of swim training. Each subject demonstrated a singular way in responding to the training load by combining the different energetic confounders during such period. So, training prescription should focus on individual background, rather than in the mean level presented by a swimming team.

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Chapter 6

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

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 (TP_1, TP_2, TP_3) 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 x 200 m swims was applied to assess the energetic and biomechanical data. Measurements were made of: (i) velocity at the 4-mmol of lactate levels (V_4), stroke index at V_4 ($SI@V_4$) and propelling efficiency at V_4 ($\eta_p@V_4$), as energetic estimators; (ii) stroke length at V_4 ($SL@V_4$) and stroke frequency at V_4 ($SF@V_4$), 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 $SI@V_4$ in TP_1 and TP_3. The tracking based on k values was high only for the $SI@V_4$. 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 $SI@V_4$ may be used as an indicator of performance variation.

Keywords: *Performance, elite swimmers, biophysics profile, tracking, freestyle*

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. Even so, 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 (Minghelli and Castro 2006). Few others studies investigated at the same time both domains (Wakayoshi et al. 1993; Termin and Pendergast 2000; Anderson et al. 2008; Latt et al. 2009a; Latt et al. 2009b). Decreases in blood lactate concentrations related to swimming velocity were observed after six 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@V_4) 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; Latt et al. 2009b).

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 (Sánches & 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: (i) track the stability and the changes of performance, energetic and biomechanical profiles from international and national level swimmers during a full competitive season; (ii) compare the performance, energetic and biomechanical profiles between both cohort groups. It was hypothesized: (i) a performance enhancement throughout the competitive season, along with a high stability in energetic and biomechanical variables and; (ii) 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 as Int level swimmers 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 ± 1.53 $kg.m^{-2}$ 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 as Nat level swimmers (n = 6; 20 ± 3.25 years old; 1.77 ± 0.05 m of height; 72.93 ± 6.34 kg of body mass; 23.19 ± 1.80 $kg.m^{-2}$ 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: (i) December 2009 (TP_1); (ii) March 2010 (TP_2) and; (iii) June 2010 (TP_3). The TP_1, TP_2 and TP_3 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: (i) training units (tu) (TP_1: 8.88 ± 0.64 $tu.wk^{-1}$; TP_2: 9.00 ± 0.85 $tu.wk^{-1}$; TP_3: 8.73 ± 0.90 $tu.wk^{-1}$); (ii) volume (TP_1: 44.53. ± 6.45 $km.wk^{-1}$; TP_2: 43.87 ± 5.86 $km.wk^{-1}$; TP_3: 43.61 ± 8.25 $km.wk^{-1}$); (iii) low aerobic

tasks (TP_1: 39.06. ± 3.11 $km.wk^{-1}$; TP_2: 38.41 ± 2.82 $km.wk^{-1}$; TP_3: 39.14 ± 3.61 $km.wk^{-1}$); (iv) intensity corresponding to their aerobic capacity (TP_1: 2.35 ± 0.95 $km.wk^{-1}$; TP_2: 2.16 ± 0.96 $km.wk^{-1}$; TP_3: 1.55 ± 0.41 $km.wk^{-1}$); (v) intensity corresponding to their aerobic power (TP_1: 1.41 ± 0.38 $km.wk^{-1}$; TP_2: 1.25 ± 0.38 $km.wk^{-1}$; TP_3: 1.00 ± 0.28 $km.wk^{-1}$); (vi) lactate tolerance training (TP_1: 0.76 ± 0.26 $km.wk^{-1}$; TP_2: 0.80 ± 0.18 $km.wk^{-1}$; TP_3: 0.89 ± 0.15 $km.wk^{-1}$); (vii) intensity of maximal lactate power (TP_1: 0.27 ± 0.05 $km.wk^{-1}$; TP_2: 0.29 ± 0.08 $km.wk^{-1}$; TP_3: 0.50 ± 0.35 $km.wk^{-1}$) and; (viii) velocity training (TP_1: 0.68 ± 0.22 $km.wk^{-1}$; TP_2: 0.95 ± 0.17 $km.wk^{-1}$; TP_3: 0.54 ± 0.16 $km.wk^{-1}$). Technical training was performed during the low aerobic tasks, including practicing technical drills.

On each occasion the swimmers completed an intermittent set of 7 x 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 pacemaker 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 two weeks.

Energetics Data Collection

Energetics assessment included the analysis of the velocity at 4 $mmol.L^{-1}$ of blood lactate concentration (V_4) as an aerobic capacity indicator, the stroke index and the propelling efficiency at the same velocity ($SI@V_4$ and $\eta_p@V_4$, respectively) as swim efficiency estimators. To determine the V_4, capillary blood samples were collected from the ear lobe to determine the lactate concentrations $[La^-]$ with an auto-analyzer (YSI 1500 L, Yellow Springs, Ohio, 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 mml.L^{-1}). The [La$^-$] values allowed the individual V4 measurement interpolating the average lactate value (4 mml.L^{-1}), with the exponential curve of lactate/speed. The SI@V$_4$, considered as one of the swimming stroke efficiency indexes, was adapted and computed as (Costil et al. 1985):

$$SI @ V_4 = V_4 \cdot SL @ V_4 \tag{1}$$

where SI@V$_4$ is the stroke index at V$_4$ (m^2.c^{-1}.s^{-1}), V$_4$ is the 4 mmol.L^{-1} lactate concentration velocity (m.s^{-1}) and the SL@V$_4$ is the stroke length at V$_4$ (m). The η_p@V$_4$ was also estimated as being (Zamparo et al. 2005):

$$\eta_p @ V_4 = \left(\frac{V_4 \cdot 0.9}{2\pi \cdot SF @ V_4 \cdot l} \right) \cdot \frac{2}{\pi} \tag{2}$$

where V$_4$ is the 4 mmol.L^{-1} lactate concentration velocity (m.s^{-1}), the SF@V$_4$ is the stroke frequency at V$_4$ (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 (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 V$_4$ and stroke length at V$_4$ (SF@V$_4$ and SL@V$_4$, 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@V$_4$ was calculated by the interpolation of the SF value in the V$_4$ by the curve SF-velocity.

SL@V_4 was estimated as being (Craig et al. 1985):

$$SL@V_4 = \frac{V_4}{SF@V_4}$$

(3)

where SL@V_4 is the stroke length at V_4 (m), V_4 is the 4 mmol.L^{-1} lactate concentration velocity (m.s^{-1}), and the SF@ V_4 is the stroke frequency at V_4 (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: (i) mean stability and; (ii) 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: (i) excellent if k $\geq$ 0.75; (ii) moderate if 0.40 $\leq$ k < 0.75 and; (iii) low if k < 0.40. The Ranking Spearman Correlation Coefficient was also computed as another normative stability parameter. Qualitatively, stability was considered to be: (i) high if $r_s \geq 0.60$; (ii) moderate if $0.30 \leq r_s < 0.60$ and; (iii) low if $r_s < 0.30$, 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

Fig 1 presents 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 time periods when pair wised. However, values with statistical significance were observed when comparing both cohort groups: TP$_1$ (Int200m = 115.38 ± 4.33 s; Nac200m = 121.43 ± 2.46 s; P = 0.03), TP$_2$ (Int200m = 115.85 ± 3.12

s; Nac200m = 121.25 ± 2.60 s; P = 0.03) and TP_3 (Int200m = 115.18 ± 3.16 s; Nac200m = 121.41 ± 3.02 s; P = 0.02).
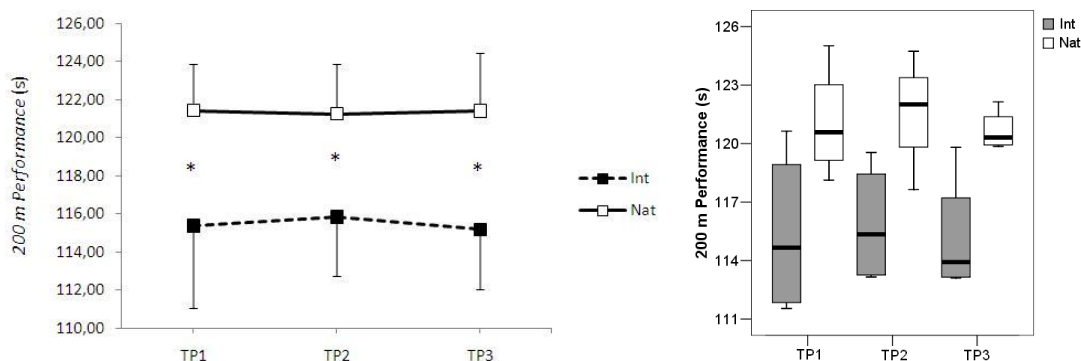

Figure 1. Variation of the 200-m freestyle performance during the competitive season; * Indicates significant difference between Int and Nat swimmers performances (TP_1 p = 0.03; TP_2 p = 0.03; TP_3 = 0.02).

Fig 2 presents the energetic variables variation throughout the competitive season. No significant variations were observed between pair wised time periods. The only exception was the comparison of Nat $SI@V_4$ between TP_2 and TP_3 ($SI@V_{4TP2}$ = 3.78 ± 0.26 $m^2.c^{-1}.s^{-1}$; $SI@V_{4TP3}$ = 3.88 ± 0.22 $m^2.c^{-1}.s^{-1}$; P = 0.05). Very close to the statistical significance cut-off value adopted were also verified for Nat $SI@V_4$ between the TP_1 and TP_2 ($SI@V_{4TP1}$ = 3.75 ± 0.29 $m^2.c^{-1}.s^{-1}$; $SI@V_{4TP2}$ = 3.78 ± 0.26 $m^2.c^{-1}.s^{-1}$; P = 0.06) and between TP_1 and TP_3 ($SI@V_{4TP1}$ = 3.75 ± 0.29 $m^2.c^{-1}.s^{-1}$; $SI@V_{4TP3}$ = 3.88 ± 0.22 $m^2.c^{-1}.s^{-1}$; P = 0.07). Significant differences were demonstrated for V4 when comparing both groups on TP_2 ($IntV_4$ = 1.48 ± 0.03 $m.s^{-1}$; $NacV_4$ = 1.42 ± 0.06 $m.s^{-1}$; P = 0.05). Remaining variables presented no significant values. However, once again, the $SI@V_4$ on the TP_1 ($IntSI@V_4$ = 4.12 ± 0.26 $m^2.c^{-1}.s^{-1}$; $NacSI@V_4$ = 3.75 ± 0.29 $m^2.c^{-1}.s^{-1}$; P = 0.06) and TP_3 ($IntSI@V_4$ = 4.22 ± 0.21 $m^2.c^{-1}.s^{-1}$; $NacSI@V_4$ = 3.88 ± 0.22 $m^2.c^{-1}.s^{-1}$; P = 0.07) was very close to the statistical significance cut-off value.
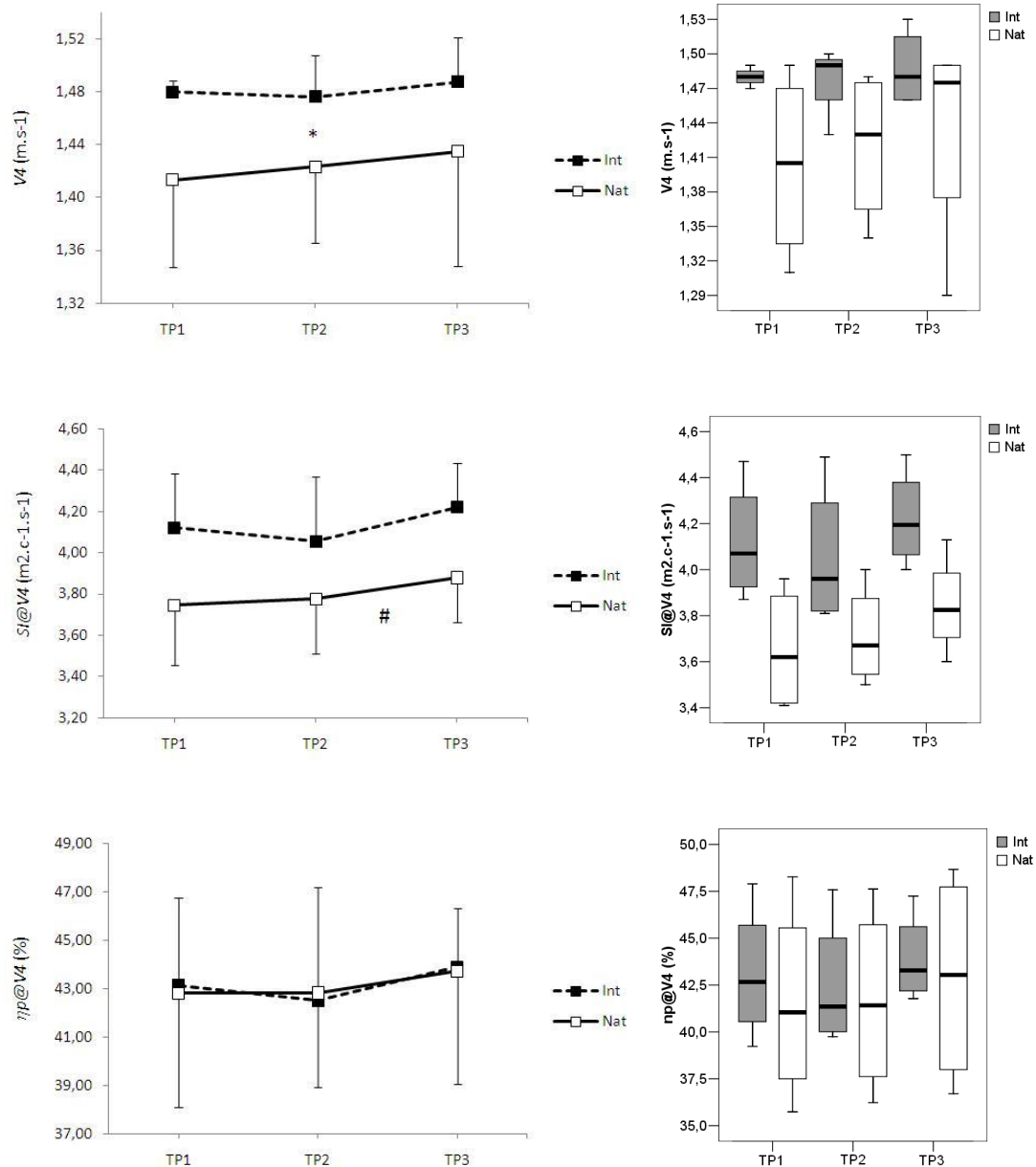
Figure 2. Variation of energetic variables during the three time periods. * Indicates significant difference from International and National level swimmers V_4 (TP_2 p = 0.05). # Represents significant differences in Nationals SI@V_4 between TP_2 and TP_3 (p = 0.05).

Fig 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@V_4 and increased SL@V_4.
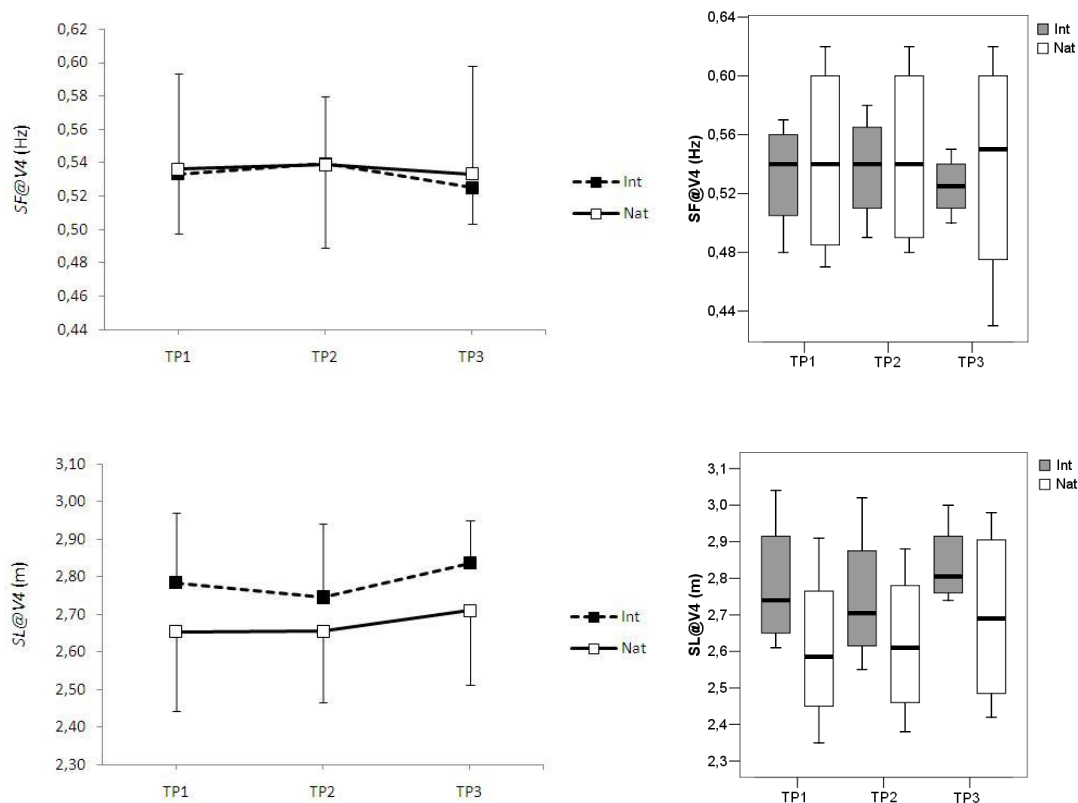
Figure 3. Variation of biomechanical variables across the season.

Table 1 presents the relative changes (i.e. %) in performance, energetics and biomechanics throughout the season from TP_1 to TP_2, TP_2 to TP_3 and the overall time period. From the TP_1 to TP_2 the Int group presented decreases in the relative change for almost all variables. The only exception was the $SF@V_4$ (1.05 ± 5.14 %). On the other hand, the opposite trend was observed for Nat swimmers. From the TP_2 to TP_3 both cohort groups revealed increases in all variables. The $SI@V_4$ presented the highest change during the overall season ($IntSI@V_4$ = 2.70 ± 5.98 %; $NatSI@V_4$ = 3.70 ± 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 V_4 (k = 0.23 ± 0.26) and $SL@V_4$ (k = 0.39 ± 0.26). Moderate values were verified for the 200 m event (k = 0.49 ± 0.26), $SF@V_4$ (k = 0.54 ± 0.26), and $\eta_p@V_4$ (k = 0.60± 0.26). Only the $SI@V_4$ presented a high stability (k = 0.80 ± 0.26).

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

		Between Time Periods (%)		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
V_4	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@V_4	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@V_4	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@V_4	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@V_4	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

Table 2 presents the Spearman Correlation Coefficient values for pair wised 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 ($0.56 \leq r_s \leq 0.88$). Both energetic and biomechanical values measured were also relatively high: SI@V_4 ($0.77 \leq r_s \leq 0.95$), η_p@V_4 ($0.76 \leq r_s \leq 0.93$), SF@V_4 ($0.65 \leq r_s \leq 0.90$), SL@V_4 ($0.65 \leq r_s \leq 0.92$). The only exception was the V_4 with low-high stability ($0.33 \leq r_s \leq 0.82$).

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*
V_4 (m.s^{-1})	0.82**	0.33	0.42
SI@V_4 (m^2.c^{-1}.s^{-1})	0.95**	0.83**	0.77**
ηp@V_4 (%)	0.93**	0.86**	0.76*
SF@V_4 (Hz)	0.90**	0.65*	0.66*
SL@V_4 (m)	0.92**	0.72*	0.65*

* P < 0.05; ** P < 0.01

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 $SI@V_4$ 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 of external load and technical ability reached, Nat and Int swimmers have some difficulties in promote huge improvements in a single season. For some cases, swimmers from this competitive level are training 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 ± 3.57 %) from TP_1 to TP_2 and thereafter improves (0.57 ± 1.16 %) from TP_2 to TP_3. 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 TP_1 to TP_2 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 not demonstrated the same trend. Since a reduce

sample size median values are more informative than mean ones. Specific swimmers imposed a statistical inference data conducting to the acceptation of the null hypothesis. Thus, some caution should exist when interpreting some inferential data as for this case. Despite a relative change (values from TP_2 to TP_3 showed a decline, 0.19 ± 3.87 %), from a qualitative point of view most national level swimmers demonstrated better 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 (TP_1 P = 0.03; TP_2 P = 0.03; and TP_3 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 V_4 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 V_4 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 TP_3 it was observed a slight decline in Int swimmer's V_4. 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 TP_3 may have contributed for this V_4 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 V_4 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 V_4 when compared to the Nat. Indeed, in the TP_2 significant differences were observed between both groups (P = 0.05). V_4 represents a unique combination of $SF@V_4$ and $SL@V_4$ (Craig et al. 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).

$SI@V_4$ and $\eta_p@V_4$ are overall indicators of swimming efficiency. Both variables presented slight changes over the course of the study. $SI@V_4$ has double effect from V4 (Costill et al., 1985). Slight and even non-meaningful changes in V_4 and $SL@V_4$ leaded to changes in $SI@V_4$ near of the statistical significance. Indeed, significant meaning (P = 0.05) was observed for the Nat $SI@V_4$ from the TP_2 to TP_3. The higher time spent in low aerobic tasks related to technical training in the final stage of the season may explain this improvement in $SI@V_4$ and $\eta p@V_4$, resulting into 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 TP_2 to TP_3 was determinant to increase swimming efficiency. To the best of our knowledge, limited longitudinal data are available regarding the $SI@V_4$ and $\eta p@V_4$ 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; Latt et al., 209b). However, several cross sectional studies have already suggested that Int swimmers present higher SI and ηp values than Nat ones (e.g. Toussaint 1990; Sánches 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 $SL@V_4$ and a decrease in the $SF@V_4$ 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 V_4 increased, there was less choice of combining $SF@V_4$ and $SL@V_4$. So, the single possibility was to increase in a higher range the $SL@V_4$ reducing the $SF@V_4$. The $SF@V_4$ 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@V_4 and SL@V_4 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@V_4 was higher for the Int swimmers (2.15 ± 4.45 %). Additionally, Int swimmers presented a higher SL@V_4 and reduced SF@V_4 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 m 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 delivery 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 with the possibility of a swimmer to demonstrate a "stable" profile in their characteristics when concerning to other swimmers (if he remains on their specific track of competitive level across the season, or if 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 V_4 and SL@V_4 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@V_4 high k values were demonstrated. Despite the SI@V_4 improvement observed for the Nat cohort, Int swimmers were able to increase their SI@V_4 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@V_4 values near of the statistical significant

were demonstrated in TP_1 and TP_3 when comparing both groups, the $SI@V_4$ 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 V_4 ($0.33 \leq r_s \leq 0.82$) 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; Latt et al. 2009b). 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 five and seven year's time frame, respectively. The low-high range in V_4 stability can be related to several episodes that might play a major role such as: (i) an acute or a chronic injury (Wolf et al. 2009); (ii) illness (Hellard et al. 2010); (iii) overtraining (Pelayo et al. 1996) or; (iv) 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 $SI@V_4$ can be used as an indicator of performance variation throughout the competitive season.

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General Discussion and Conclusion

The main aim of this thesis was to conduct a longitudinal evaluation of performance, energetic and biomechanical profiles of elite swimmers, aiming to understand the interplay among these domains. The main conclusions drawn were: (i) the few existing longitudinal studies in swimming "science" present low quality scores; (ii) the age of 16 years-old and the third seasons of an Olympic cycle were important chronological milestones regarding the performance progression; (iii) elite swimmers only demonstrated slight changes in performance, energetic and biomechanical profiles at least for two seasons; (iv) the magnitude of change was dependent on the duration of the intervention, type of training done and competitive level; (v) each swimmer demonstrated a different changing profile in response to the training load applied and; (vi) additional improvements in the annual 200 m performance were related with the ability to induce novel adaptations in the aerobic fitness, stroke kinematic and efficiency factors.

The starting point of this thesis was to conduct a systematic review based on the longitudinal papers previously published about the performance, energetics and biomechanics in elite swimmers (Chapter 1). Our research concluded that there are few longitudinal studies in the swimming "science" domain. Moreover, most of those swimming interventions presented low quality scores when compared to intervention studies in health and social sciences. This happens mostly because swimming studies not have into consideration some complex procedures used on a regular basis on other scientific domains and also have poor way of reporting the intervention. For this reason we tried to fulfill that gap in our following experimental studies by improving some items that are critical to increase the research quality. Tracking down the performance progression it is an useful information for coaches since it allows the determination of specific chronological milestones that might help to predict the swimmer's success. A lack of meaningful improvement in freestyle performance is evident starting at the age of 16 years-old (Chapter 2). This suggests that it is possible to determine the swimmer competitive level at adult age based on the 16 years' performances with higher accuracy. The progression in freestyle performance for a World-ranked swimmer shows a deceleration around the third season of an Olympic cycle (Chapter 3). This indicates that when considering the race times at the third season of an Olympic cycle, it is possible to predict with higher accuracy the Olympics' year performance. In this case, the improvement in race times (3-4%) (Chapter 3) it is not so obvious when compared to the progression from childhood to adulthood (14-19%) (Chapter 2). The chapter 3 is focused on the performance progression of

swimmers that are already at their adult age (i.e. peak performance or very close to it). On the contrary, the chapter 2 analyzes part of the elite swimmers' performance during their formative years. Probably, during such time frame, the maturational development may display an important role by enhancing performance in a higher range than in adult ages. Nevertheless, it should be stressed out that a 3-4% of improvement for World-ranked swimmers represents a meaningful change while competing at higher international level.

In the experimental studies conducted (Chapter 4, Chapter 5 and Chapter 6) only slight changes were determined for the performance and most of the energetic and biomechanical variables assessed. Tracking adaptations in elite swimmers during one competitive season or more presents an extra-challenge. In this subjects, the energetic, biomechanical and performance status are characterized by extreme values at their upper limits, and the possibility to obtain substantial changes is limited. Probably elite swimmers have reached greater energetic and biomechanical capacities at the career peak, due to several years/decade of systematic and hard training. Although there is a little margin of improvement for this kind of subjects, the magnitude of change seems to be dependent on other issues.

The duration of the intervention is one determinant aspect to be considered when analyzing the significant meaning of change (Chapter 1). It seems that with a higher time-frame to track down the selected variables of an intervention program, it will be easier to verify significant differences. Probably, with a two years intervention we can detect broader improvements than within one single year. No significant adaptations were found for the La_{peak} after one season of training (Chapter 5). On the other hand, two consecutive seasons were sufficient to show significant adaptations in the La_{peak} of the same swimmers (Chapter 4). The magnitude of change in performance of elite swimmers for a two season time period was 0.82% (Chapter 4). However, that change was even smaller (0.36%) when considering one single season of training (Chapter 5). Based on this evidences, it should be expected low gains in performance, energetic and biomechanical status for studies with shorter time frames. Moreover, some of those gains reached within each year are lost in the off-season period (Anderson et al., 2006). Nevertheless, the net average annual gains are cumulative from one year to the next one and consequently increase the chance to obtain significant differences in longer interventions.

The magnitude of change seems also to be dependent on the type of training done (Chapter 1). Contents such as volume, intensity and frequency are among the factors described by coaches in their periodization design (Mujika, 1998). An increase in training intensity from the first to the second season, along with maintenance in the volume and frequency, was effective to enhance in a larger rate the performance, energetic and biomechanical profiles (Chapter 4).

This result it is in agreement with previous observations (Mujika et al., 1995) reporting that the improvement in elite swimmer's performance it is significantly correlated with the mean intensity of the training season, but not with training volume or frequency. Indeed, high training volumes seem to have no advantage compared to high intensity training with lower volumes in this kind of athletes (Costill et al., 1991; Faude et al., 2008). Since the majority of the competitive swimming events last less than 3 minutes at high intensity, training programs should imply sets with intensities nearly or similar to those used on main events to induce novel adaptations in subjects from this competitive level.

The swimmers competitive level seems to be another issue defining the magnitude of change. Among those grouped in the "elite definition" we can distinguish international swimmers from national level ones. Based on this classification, it was observed that national swimmers demonstrated a higher margin of change within the season in the most energetic and biomechanical variables assessed (Chapter 6). An annual increase in the efficiency with significant meaning was determined for this cohort. It seems that national level swimmers just need the "sufficient training stimulus" to demonstrate a constant change in their performance, energetic and biomechanical characteristics. On other hand, the international ones require the "correct training stimulus" to have a positive change on their form. Despite their lower magnitude of change, international swimmers showed better values than nationals throughout the overall season. Earlier cross-sectional observations have already reported that international swimmers are more economical (Toussaint, 1990; Fernandes et al. 2006a) and efficient (Sánches and Arellano, 2002; Fernandes et al., 2006) when compared to the lower level ones. Thus, the consideration of the swimmer competitive level should be of major interest for training prescription.

The assessment of individual trends is another important topic of training diagnosis and should also be for sport performance researchers. With the identification of the swimmer's individual energetic and biomechanical characteristics it becomes easier to adequate prescription for further adaptations. Different changing profiles were determined for the performance (Chapter 2, Chapter 3), energetics (Chapter 4, Chapter 5, Chapter 6) and biomechanics (Chapter 4, Chapter 6) of each swimmer in their response to training. Similar trend was found in earlier interventions (Anderson et al., 2006), suggesting a high variability in swimmers response according to age, gender and competitive level. It seems that each swimmer uses the most freely chosen energetic and biomechanical combination to maintain the performance at higher levels throughout the season. Literature suggests that swimming efforts from 30 seconds to 4 minutes require the contribution from both aerobic and anaerobic systems

(Troup, 1991). An increased aerobic capacity and lower anaerobic one, or vice versa, are different ways in combining the energetic profile to reach higher velocities. Swimming velocity also relies on the SF and SL combination (Craig and Pendergast, 1979). Increases or decreases in velocity can be accomplished by an increased SL and lower SF, or vice versa. So, based on this evidences, training prescription should focus on individual background rather than in the mean level presented by a swimming team.

Recent findings confirmed that performance is strongly linked to energetic variables, since these in turn, are dependent on the biomechanical behavior (Barbosa et al., 2010b). From the experimental results of this thesis, the aerobic fitness (V_4 and vVO$_2$max), the stroke kinematics (SL and SF) and efficiency factors (SI), were the measures that predicted with higher accuracy the changes in longitudinal 200 m performance. Regarding the 200 m freestyle race, previous studies determined a substantial contribution (66%) from the aerobic energy source for the final outcome (Figueiredo et al. 2011). It is expected that, an improved aerobic capacity, indicated by an increase in V_4, will be the major energetic adaptation for the performance enhancement within and between seasons (Chapter 4). Additionally, the use of vVO$_2$max as an aerobic power measure should not be neglected, and can be considered a reliable tool to monitor performance adaptations within the season (Chapter 5). Positive effects in performance were also evident due to biomechanical adaptations within the year. The SL and SF were the main biomechanical predictors of the 200 m freestyle performance (Chapter 4). Since there seems to exist a high variability in the swimmers response to training, improvements in swimming velocity can be achieved by manipulation both aspects. Indeed, those kind of changes have been demonstrated by elite male swimmers in previous studies (Termin and Pendergast, 2000). It showed to have benefits on short distance freestyle performance from one year to another. Such adaptations will also determine the efficiency during the stroke cycle. The SI and the η_p were the variables assessed as efficiency swimming indicators. However, the SI was the one that distinguished better the performances according with the swimmers' competitive level (Chapter 6).

Taking into account the considerations the above discussion, it can state that the specific conclusions of the present thesis were:

- the few existing longitudinal studies in swimming "science" domain presented low quality scores when compared to other scientific areas;

- sixteen years-old was the age at which the ability to predict adult performance increases markedly;

- Stabilization in freestyle performances was evident at the third season of an Olympic cycle. Based on those race times it is possible to predict with higher accuracy the Olympics' year performance.

- Elite swimmers only demonstrated slight changes in their performance, energetic and biomechanical profiles at least for two seasons of training;

- The magnitude of change was dependent on the duration of the intervention. When increasing the time frame analysis, the magnitude of change increased and the stability decreased.

- The magnitude of change was dependent on the type of training done. Training based on high intensity was the best way to develop both energetic and biomechanical profiles.

- The magnitude of change was dependent on the swimmers' competitive level. Higher level swimmers demonstrated less margin of change than lower level ones;

- There was high variability in the individual response to the training load applied. Each swimmer demonstrated a different changing profile to annual training.

- The improvement of aerobic fitness (V_4) and the stroking kinematic factors (SF and SL) were the best ways to promote additional gains in the 200 m freestyle performance.

As a main conclusion it can be stated that the improvement in elite swimmers' performance is most notorious in their formative years than at adult age. At this point the significant adaptations are only evident in interventions with longer time frames. Nevertheless, each swimmer seems to respond differently, by combining the energetic and biomechanical profiles in order to enhance performance. In summary, it seems that there is not one single recipe (i.e., annual training plan and energetics-biomechanical strategies) for all swimmers enhance performance, and after all: "one size does not fit all". Elite swimmer coaches should know the differences between each one of the athletes and train them accordingly.

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