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Longitudinal Assessment of Masters Swimmers
Monitoring the energetics, biomechanics and performance over
a season

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Abstract

The aim of this investigation was to conduct a longitudinal assessment of the performance, energetics and biomechanic profiles of masters swimmers, over one full season. The thesis includes the following studies: (i) review of literature; (ii) identification of the energetic and biomechanical contributions for longitudinal swimming performance; (iii) analysis of the changes of the energetic profile over a season; and (iv) analysis of the effect of gender, energetic and biomechanics on swimming performance. Results suggest that, for masters swimmers: i) there are no longitudinal studies related with changes in the performance and the factors influencing it within and/or between seasons; ii) cross-sectional studies related with energetics, biomechanics, and performance are scarce and present low quality scores; iii) swimmers improved significantly their 200m freestyle performance over a season; iv) although we found some improvements in energetic variables over the season, the performance seems to be more dependent on technical parameters; v) male swimmers have better performance, higher stroke length, stroke index and maximal blood lactate concentration after exercise than female counterparts; vi) gender has a significant effect on the stroke length, stroke index and maximal blood lactate concentration after exercise.

Keywords

Masters Swimmers, Performance, Metabolic Determinants, Biomechanics Determinants, Gender Differences, Training, Swimming Season

Resumo

O objetivo deste trabalho foi a realização de uma avaliação longitudinal da performance e dos perfis energético e biomecânico de nadadores do escalão masters durante uma época desportiva. Esta tese inclui os seguintes estudos: (i) revisão da literatura; ii) identificação das contribuições energéticas e biomecânicas para a performance; iii) análise das alterações do perfil energético durante uma época; iv) análise do efeito de género, energética e biomecânica sobre a performance. Os resultados sugerem que, para nadadores masters: (i) não existem estudos longitudinais relacionados com alterações na performance e os fatores que a influenciam durante e/ou entre épocas; ii) os estudos transversais existentes relacionados com a energética, a biomecânica e a performance são escassos e apresentam um baixo índice de qualidade; iii) durante a época, os nadadores melhoraram significativamente a sua performance nos 200 metros livres; iv) os fatores energéticos melhoraram ao longo da época, embora, neste escalão etário, a performance pareça depender mais dos aspetos relacionados com a técnica de nado; v) os nadadores do sexo masculino têm melhor performance e valores superiores de distância de ciclo, índice de nado e concentração máxima de lactato sanguíneo após o exercício do que os nadadores do sexo feminino; vi) o género tem um efeito positivo sobre a distância de ciclo, o índice de nado e a concentração máxima de lactato sanguíneo após o exercício.

Palavras-chave

Nadadores Masters, Performance, Determinantes Metabólicas, Determinantes Biomecânicas, Diferenças de Género, Treino, Época Desportiva

Resumen

El objetivo de este trabajo fue la realización de una evaluación longitudinal de la performance y de los perfiles energético y biomecánico de nadadores de la categoría máster. Esta tesis incluye los siguientes estudios: (i) revisión bibliográfica; ii) identificación de las contribuciones energéticas y biomecánicas para la performance; iii) análisis de los cambios en el perfil energético durante una temporada; iv) análisis del efecto de género, biomecánica y energética sobre la performance. Los resultados sugieren, para nadadores máster, que: (i) no hay estudios longitudinales relacionados con cambios en la performance y los factores que influyen en ella durante y/o entre temporadas; ii) los estudios transversales existentes relacionados con la energética, la biomecánica y la performance son escasos y tienen un bajo nivel de calidad; iii) durante la temporada, los nadadores mejoraron significativamente su desempeño en los 200 metros libre; iv) los factores energéticos mejoraron durante la temporada, aunque en este grupo etario, la performance parece depender más de los aspectos relacionados con la técnica de nado; v) los nadadores masculinos tienen una mejor performance y valores superiores de distancia de ciclo, índice de nado y concentración máxima de lactato en la sangre después del ejercicio que las nadadoras; vi) el género tiene un efecto positivo en la distancia de ciclo, el índice de nado y la concentración máxima de lactato en la sangre después del ejercicio.

Palabras clave

Nadadores Máster, Performance, Determinantes Metabólicas, Determinantes Biomecánicas, Diferencias de Género, Entrenamiento, Temporada Deportiva

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List of Abbreviations

<i>Aer</i>	Aerobic contribution
<i>AnAl</i>	Anaerobic alactic contribution
<i>AnL</i>	Anaerobic lactic contribution
ATP	Adenosine triphosphate
<i>D</i>	Distance
E_{tot}	Total energy expenditure
La_{peak}	maximal blood lactate concentration after exercise
La_{net}	Difference between the lactate measured at the end of 200 m and the lactate at rest
LDH	Lactate dehydrogenase
K	Kappa Index
<i>M</i>	Mass
O ₂	Oxygen
O ₂ Eq	Oxygen equivalent
PCr	Phosphocreatine concentration
PFK	Phosphofructokinase
QI	Quality index
<i>SF</i>	Stroke frequency
<i>SL</i>	Stroke length
<i>SI</i>	Stroke index
<i>t</i>	Time duration
TP	Time period
TP ₁	Time period in December
TP ₂	Time period in March
TP ₃	Time period in June
<i>v</i>	Swimming velocity
v_4	Velocity at 4 mmol·l ⁻¹ of blood lactate concentration
v_{200}	200 m freestyle swimming velocity
VO ₂	Oxygen uptake
VO _{2max}	Maximal oxygen uptake
VO_{2net}	Difference between the oxygen uptake measured during exercise and at rest
τ	Time constant of phosphocreatine splitting at work onset
% <i>Aer</i>	Partial contribution of aerobic energy source
% <i>AnAl</i>	Partial contribution of anaerobic alactic energy source
% <i>AnL</i>	Partial contribution of anaerobic lactic energy source
η_p	Propelling efficiency of the arm stroke

Chapter 1 - General Introduction

Masters athletes are subjects who systematically train for, and compete in, organized forms of competitive sport specifically designed for adults and older adults (Reaburn and Dascombe, 2009). Competitions for masters have increased concurrently with the increase of aging population (Ransdell *et al.*, 2009). Regardless of the activity level, the impairment in athletic performance is inevitable with age whereby the study of masters athletes represents the chance to investigate the effects of age controlling the effect of a sedentary lifestyle or disuse (Tanaka and Seals, 2008).

Swimming is often considered as a sport targeting older adults once it is a non-weight-bearing activity reducing the risk of muscle-skeletal injury (Rubin *et al.*, 2013). Moreover, it is claimed that there are benefits for the cardiovascular and musculoskeletal systems (Gatta *et al.*, 2006) and improvements in the physical fitness, such as decrease of body fat, increase of limb and trunk muscle strength and reduction of elevated blood pressure (Rubin and Rahe, 2010).

In competitive swimming, training sets are developed to build-up physiologic systems and enhance the technique and hence excel within and between seasons (Costa *et al.*, 2013). The training of masters swimmers presents some specific features: lower engagement in regular exercise (DiPietro, 2001), longer rest periods between sets, lower volume (Rubin and Rahe, 2010), less training sessions per week and main focus on building-up aerobic fitness (Weir *et al.*, 2002). Considering these characteristics, it is important to learn if this type of training will influence the performance, energetics and biomechanics. At least in young age-group swimmers and adult/elite swimmers, it was reported that such relationship exists. Performance improvements were found within a season in elite swimmers (Anderson *et al.*, 2006; Costill *et al.*, 1991; Pyne *et al.*, 2001, 2004). Costa *et al.* (2012b) reported no significant variation in performance throughout the season. Considering the energetic profile, velocity at 4 mmol·l⁻¹ of blood lactate concentration (v_4) (Anderson *et al.*, 2006; Costill *et al.*, 1991; Pyne *et al.*, 2001), maximal blood lactate concentration after exercise (La_{peak}) (Anderson *et al.*, 2006; Costa *et al.*, 2012b) and total energy expenditure (E_{tot}) (Costa *et al.*, 2013) improvements were registered over a season. However, v_4 and La_{peak} presented no significant variation (Costa *et al.*, 2013) and maximal oxygen uptake (VO_{2max}) remained unchanged within the season (Costa *et al.*, 2013; Costill *et al.*, 1991). Regarding the biomechanics, studies with elite swimmers reported the increase of stroke frequency (SF) and decrease of stroke length (SL) (Anderson *et al.*, 2006) while no significant changes were found in biomechanics parameters in the study of Costa and co-workers (Costa *et al.*, 2012b).

However, so far, literature is scarce on the topic for masters athletes, in general, and swimmers in particular.

To assess the changes that may occur throughout a season, longitudinal studies are required since the cross-sectional interventions are less informative about the cause-effect relationship in a long-term perspective (Costa *et al.*, 2013). The available longitudinal literature on masters swimmers focuses mainly on age-related changes in swimming performance. Thus, it was reported that 50 m performance was influenced by aging (Favaro and Lima, 2005), and 50 m and 1500 m freestyle swimming performance declined with advancing age, although in 50 m the decline in performance was smaller than in 1500 m (Donato *et al.*, 2003). Moreover, it was reported that male and female swimmers improved their ability during the early years of participation (Rubin *et al.*, 2013). To the best of our knowledge, there are no scientific evidences related to the performance progression within or between seasons in masters swimmers (study 1).

To fill this gap, the changes that may occur over a season in energetics and biomechanics profiles, and performance were assessed, to learn if training influences, or not, the studied parameters (study 2). The available longitudinal literature on masters swimmers focuses especially on the effect of age and gender on performance and no studies have been conducted so far to determine the masters swimmers energetic and biomechanical adaptations to annual training. The studies related with energetics and biomechanics parameters were cross-sectional. Thus, among the energetics factors La_{peak} , v_4 and VO_{2max} were included. Literature reported that lactate production decreased with age (Reaburn and Dascombe, 2009). However, it was reported that as age increases, La_{peak} may be maintained with high-intensity sprint swim training (Reaburn and Mackinnon, 1990). Among the biomechanical variables, SF , SL , index stroke (SI) and propelling efficiency of the arm stroke (η_p) were considered. It was mentioned that SF and SL were influenced by age (Favaro and Lima, 2005; Gatta *et al.*, 2006), although it seems that ageing affects more SF than SL (Gatta *et al.*, 2006). In addition, until 60 years, masters swimmers presented higher η_p than swimmers with 60-80 years (Zamparo *et al.*, 2012a).

After analyzing the changes of the factors affecting the performance throughout the season, we tried to find if the same training load has different effects in men and women, regarding energetics and biomechanics profiles, and performance (studies 3 and 4). Thus, the gender gap emerged as an interesting topic of investigation, to find out if the effects of ageing are similar in male and female swimmers regarding muscle metabolism (study 3), energetics, swimming technique and performance (study 4). Based on cross-sectional studies it is known that males present higher La_{peak} (Benelli *et al.*, 2007) and VO_{2max} (Zamparo *et al.*, 2014) than women. Regarding the biomechanics, men presented higher swimming velocity (v), SF and SL (Zamparo, 2006) and η_p (Zamparo *et al.*, 2012a) than female. Considering the swimming

performance, literature revealed gender differences in swimming performance, mainly in short-duration events (50 m) (Donato *et al.*, 2003; Tanaka and Seals, 1997) and middle-distance (200 m) (Ransdell *et al.*, 2009), with men presenting better performances than women. To the best of our knowledge, there are no longitudinal evidences about this, remaining to be answered if there are differences in the energetics and biomechanics of male and female masters swimmers over the season.

All the physical activities to be performed require energy. Therefore the production of mechanical work is determined by the ability of the muscles cells to provide energy and, to satisfy the energy requirements of the muscles, there are three pathways: aerobic, anaerobic lactic and anaerobic alactic (Gastin, 2001). The power and capacity of the three systems are important factors in determining the swimming performance whereby large part of the training should be dedicated to the improvement of the energy production systems (Toussaint and Hollander, 1994). The energy of anaerobic alactic energy sources is derived from complete utilization of phosphocreatine (PCr) stores (Zamparo *et al.*, 2011) while La_{peak} could be used to estimate the energy derived from anaerobic lactic energy sources (di Prampero and Ferretti, 1999). The assessment of VO_{2max} is important to determine the aerobic capacity of the swimmers. The sum of aerobic and anaerobic contributions represents E_{tot} which may be defined as the amount of energy necessary to perform one task (Termin and Pendergast, 2000). Swimming events are characterized by different durations and intensities and can be described in terms of the relative contribution of aerobic and anaerobic energy sources to E_{tot} (study 3). There are evidences of the relative contribution of the energy sources in elite swimmers, but not in masters swimmers.

Following the identification of the energetics and biomechanics factors influencing the performance, it is important to analyze the effect of these parameters on performance of masters swimmers over one full season (study 4). Thus, it was found that La_{peak} correlated significantly with 50 yd performance time (Zoeller *et al.*, 2000). Regarding biomechanics factors, literature reports that SI may be used for the prediction of 50 m performance above 50 years old (Favaro and Lima, 2005), while maximal speed depends on η_p (Zamparo *et al.*, 2014). To the best of our knowledge, there no scientific evidence about it exists, based on longitudinal studies.

The main purpose of this thesis was to monitor the energetics, biomechanics and performance of masters swimmers over a season and understand the hypothetical relationships between these domains.

Chapter 2 - Review of Literature

Study 1

Energetics, Biomechanics, and Performance in Masters Swimmers: A Systematic Review

Abstract

Background: The increasing number of masters swimmers supports the need to consolidate information for the daily practice. A compilation of the current cross-sectional and longitudinal studies in this age-group would be important to assess the most important factors influencing the effectiveness of a training program.

Objectives: To summarize evidences on masters swimmers energetic, biomechanics and performance variables, gathered in selected studies.

Methods: An expanded search was conducted on six databases, conference proceedings, and department files. Sixteen studies satisfied the inclusion criteria and, hence, were selected for further analysis. A qualitative evaluation of the studies was performed by two independent reviewers using the Quality Index (QI). The studies were then classified into four domains according to the reported data: energetics (six studies), biomechanics (six studies), performance (twelve studies), and gender gap (ten studies).

Results: All the selected fifteen articles included in this review present low QI scores with a mean score of 10.5 points. Biomechanics domain obtained the higher QI (11.5 points), followed by energetics, and performance (10.6 and 9.9 points, respectively). Stroke frequency (SF) and stroke length (SL) were both influenced by aging, although SF is more affected than SL . Propelling efficiency of the arm stroke (η_p) decreased with age. Swimming performance declined with age. Regarding gender gap, males have maximal blood lactate concentrations after exercise (La_{peak}) and maximal oxygen uptake (VO_{2max}) than female swimmers. No differences were found between genders in SF , SL and η_p . Male presented a higher performance in 200 m than female swimmers.

Conclusions: This review shows the lack of longitudinal studies, specific for this age-group. The only longitudinal studies found were related to the assessment of performance over time. Studies related with energetics and biomechanics parameters in masters swimmers were all cross-sectional studies. Males presented higher aerobic and anaerobic capacity than female

swimmers. Biomechanics parameters, SF , SL and η_p , were influenced by age (decreasing) but not by gender. In the 200 m, performance declines with age and male swimmers presented a better performance than female, although this difference tends to decrease in long-distance events.

Key Points

- i) Cross-sectional studies indicate that energetics parameters were influenced by gender, with men presenting higher La_{peak} , and VO_{2max} , whereas gender had no effect on the biomechanics variables.

- ii) Energetics, biomechanics, and performance declined with age advancing.

- iii) There is a lack of longitudinal studies to evaluate the changes in energetics and biomechanics factors, affecting performance of masters swimmers.

Introduction

Sport participation in masters competitions has increased in the last couple of years due to the interest that individuals have in healthy sport participation with the advancing age (Ransdell and Wells, 1999). Research comparing masters athletes to their sedentary peers has found that many of the so-called effects of aging are actually the result of a sedentary lifestyle or disuse (Wilmore, 1991). Thus, research with masters athletes provides an excellent opportunity to investigate the effects of age in the metabolic/biomechanical determinants of performance (Zamparo *et al.*, 2012b), being possible to exclude physical inactivity as a potential confounding factor (Benelli *et al.*, 2007).

Swimming is probably the most or, at least, one of the most popular sports for masters athletes imposing little strain, and thus is particularly suitable for the elderly (Rubin and Rahe, 2010). The reasons beyond the participation of masters athletes in competitions and/or in regular exercise are the enjoyment and the health benefits (Tantrum and Hodge, 1993), as well as the will to enhance their performance (Maharam *et al.*, 1999). With aging population and the current trends towards increased physical activity in adulthood, it is important to understand the relation between age and physical performance and identify the influencing factors. Among the most important factors affecting performance in swimming events are energetics and biomechanics. Both can be monitored during training activities developed to improve the physiological and technical abilities within and between seasons (Costa *et al.*, 2013). To do this, longitudinal studies are required, since the cross-sectional interventions are less informative about the cause-effect relationship in a long-term perspective (Costa *et al.*, 2013). Another interesting topic of investigation is the gender difference in masters swimmers considering that, compared to men, women have a greater loss of muscular function and capacity (Benelli *et al.*, 2007).

There are few longitudinal studies in masters swimmers, and the ones that have been conducted aimed to analyze the effect of age and gender on performance. No studies have been conducted so far to determine the masters swimmers energetic and biomechanical adaptations to annual training. As mentioned earlier, given the increasing number of participants in this age-group and the importance of physical exercise to prevent the onset of chronic diseases, this review aims to identify gaps and trends in current research, hopefully contributing to the design of future studies. For that, a systematic review was done, summarizing evidences related to the effect of age and gender on the energetics, biomechanics and performance in masters swimmers.

Methods

A systematic search on the thematic was conducted to fulfill the suggestions and guidelines given by McGowan and Sampson (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 (researchers should be able to replicate the methods and arrive at the same results).

Search Strategy

An extensive literature search was conducted, from January 1st, 1970 until March 31st, 2014, to identify the studies in which biomechanics and energetics variables were measured in masters swimmers. This was done by using computed searches (PubMed, ISI Web of Knowledge, Index Medicus, Medline, Scopus, and Sport Discus) using the keywords longitudinal, masters swimmers, kinematics, biomechanical, energetic, physiological, performance, swimming, training season, and gender, with multiple combinations and with no language restrictions. In addition, extensive searching and cross-referencing were done by using bibliographies of the already located studies. Review articles (qualitative review, systematic review, and meta-analysis) were not considered. The energetic variables assessed were: velocity at 4 mmol·l⁻¹ of blood lactate concentration (v_4), maximal oxygen consumption (VO_{2max}), and maximal blood lactate concentration after exercise (La_{peak}). The biomechanics variables were: stroke frequency (SF), stroke length (SL), stroke index (SI), and propelling efficiency of the arm stroke (η_p).

Inclusion and Exclusion Procedures

The included studies focused on cross-sectional and longitudinal interventions on energetics, biomechanics, and performance in masters swimmers. “Masters” is defined as individuals who systematically train for, and compete in, organized forms of competitive sport specifically designed for adults and older adults (Reaburn and Dascombe, 2009). Studies based on other swimming topics, or using other chronological ages (e.g., children and elite swimmers) instead of masters swimmers, were excluded.

Regarding the research question, studies were categorized into four main groups: i) energetics; ii) biomechanics; iii) performance; iv) gender gap. The information extracted from the selected studies was based on: type of study; purpose, sample characteristics; procedures; and results.

Quality Assessment

All the studies found underwent a formal evaluation by two independent reviewers. Since there is no validated quality assessment tool suitable for sports performance, the Quality

Index (QI) 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 was 32 points. The degree of agreement in the scoring procedure was obtained based on the Kappa Index (K), and thresholds were interpreted according to Landis and Koch's suggestion (Landis and Koch, 1977) with i) $K \leq 0$ represents no agreement; ii) $0 < K \leq 0.19$, poor agreement; iii) $0.20 < K \leq 0.39$, fair agreement; iv) $0.40 < K \leq 0.59$, moderate agreement; v) $0.60 < K \leq 0.79$, substantial agreement, and vi) $0.80 < K \leq 1.00$, almost perfect agreement.

Results

Our search identified 163 relevant articles of which 147 did not meet the inclusion criteria (Figure 1). The reasons for exclusion were: being focused on other topics, such as body composition, anthropometric characteristics, skeletal muscle mass, and strength (29 studies); conducted with elite swimmers (83 studies), and participants from other chronological ages, including young swimmers (35 studies). A total of 15 studies were considered for further analysis. From these, the earliest one was published in 1990 (Reaburn and Mackinnon, 1990) and the most recent in 2014 (Mejias *et al.*, 2014).

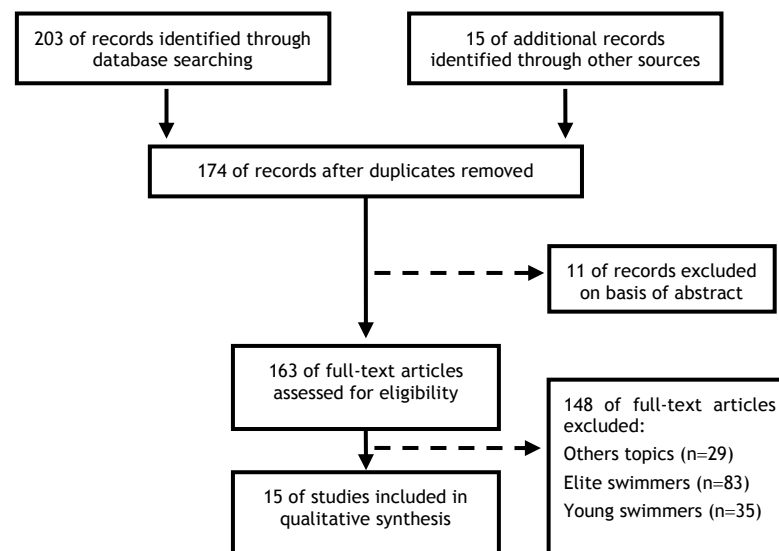


Figure 1. Flow chart of the article selection process.

The studies focusing on the energetics, biomechanics, and performance domains in masters swimmers are recent, being most of them (fourteen) conducted after 2000 (the remaining two studies were published in the 90s), indicating that, in the last 15 years, the interest in this age-group has risen. Studies were assigned to each category according to the reported

data: energetics (six studies), biomechanics (six studies), performance (twelve studies), and gender gap (ten studies). Studies presenting evidences in different domains were included in multiple categories.

Considering that no longitudinal studies reporting energetics and biomechanics domains in masters swimmers were found, we have selected cross-sectional studies related with those parameters only in masters swimmers. However, these cross-sectional studies have some limitations that may bias the results, since assessing or comparing different groups and variables at a single moment, makes them less informative about the cause-effect relationships. On the other hand, in longitudinal studies, the assessment implies a data collection at a certain number of occasions allowing to establish cause-effect relationships (Costa *et al.*, 2012a). The only longitudinal studies found reported the effects of age and gender on performance. However, these studies aimed to assess the performance over several years and not within the season.

Quality Assessment

The QI scores of all the articles included in this review ranged from 6 to 13 points, with a mean score of 10.47 points. Examining the QI by domains, we found that biomechanics was the field that obtained the higher QI (11.5 points), followed by energetics, and performance (10.6 and 9.9 points, respectively). The reliability between both reviewers showed an almost perfect agreement (0.94) in the scoring procedure. Among the five sub-scales included in the checklist, the external validity, internal validity (bias and confounding), and power were those with the poorer scores. No study selected random sampling to include subjects that would be representative for the entire population, findings cannot be generalized to the population from which the study subjects were derived, bias was not addressed in the measurement of the interventions and the outcome, or in the selection of the subjects, and the power magnitude to detect an important practical effect was not indicated. In the first sub-scale of the checklist (reporting), no study provided a list of the principal confounders and the numbers of the patients lost to follow-up.

Energetics

Table 1 presents a summary of the studies that monitored energetics factors in masters swimmers, including the assessment of the maximal blood lactate concentration after exercise ($L_{a_{peak}}$). The overall quality scores ranged between 9 and 13 points, representing a mean score of 10.5 points.

All the literature found related to energetics in masters swimmers refers to cross-sectional studies. Studies aimed to assess blood lactate concentrations at maximal speed (Benelli *et al.*, 2007; Reaburn and Mackinnon, 1990). The $L_{a_{peak}}$ values obtained in the two studies found

in literature ranged between $10.8 \pm 2.8 \text{ mmol} \cdot \text{l}^{-1}$ (Benelli et al., 2007) and $14.25 \pm 3.34 \text{ mmol} \cdot \text{l}^{-1}$ (Reaburn and Mackinnon, 1990). The studies analyzed (Benelli et al., 2007; Reaburn and Mackinnon, 1990) reveal that the $L_{a_{peak}}$ decreased with the advancing of age. In Reaburn and Mackinnon study (Reaburn and Mackinnon, 1990), the $L_{a_{peak}}$ decreased 8.4% from the age-group 25-35 years old to the oldest age-group (>56 years old). In the study of Benelli et al. (Benelli et al., 2007) the $L_{a_{peak}}$ decreased with the advancing of age was similar, but with a different rate: 17.6% in women (from age-group 40-49 to 60-69 years old) and 42.2% in men (from the age-group 40-49 to 70-79 years old).

Finally, it was reported that the velocity at $4 \text{ mmol} \cdot \text{l}^{-1}$ of blood lactate concentration (v_4), VO_{2max} and the total energy expenditure (E_{tot}) were significantly higher in the elite swimmers than in master swimmers (Mejias et al., 2014).

Table 1. Summary of the studies about the energetics of masters swimmers

Authors	Research design	Aim	Subjects	Procedures and outcomes	Findings
Reaburn and Mackinnon (1990)	Cross-sectional	Determine the effect of age on: maximal blood lactate concentration, time to reach maximal blood lactate concentration and half recovery time to baseline lactate concentration	16 males competitive masters swimmers divided in four age groups: 25-35: 31.3 yrs old 36-45: 41.0 yrs old 46-55: 49.5 yrs old >56: 67.0 yrs old	Maximal 100 m freestyle	La_{peak} may be maintained with high-intensity sprint-swim training as age increases. La_{peak} following 100 m freestyle (passive recovery): 25-35: 14.25 ± 3.34 mmol·l ⁻¹ 36-45: 15.00 ± 1.28 mmol·l ⁻¹ 46-55: 15.35 ± 2.41 mmol·l ⁻¹ >56: 13.05 ± 4.97 mmol·l ⁻¹
Benelli et al. (2007)	Cross-sectional	Measure the post-competition blood lactate concentration (La_{peak}) in masters swimmers of both genders aged between 40-79 years and relate it to age and swimming performance	108 masters swimmers 56 females (40-49: 44.1 ± 3.6 yrs old; 50-59: 53.9 ± 2.7 yrs old; 60-69: 64.6 ± 3.0 yrs old; 70-79: 73.1 ± 2.6 yrs old) 52 males (40-49: 44.2 ± 2.5 yrs old; 50-59: 54.6 ± 3.2 yrs old; 60-69: 64.8 ± 3.1 yrs old; 70-79: 73.0 ± 2.5 yrs old)	1 testing occasion 5 minutes after race participating in the 10 th World Masters Championship in 2004	Male La_{peak} : 40-49: 14.2 ± 2.5 mmol·l ⁻¹ 50-59: 12.4 ± 2.5 mmol·l ⁻¹ 60-69: 11.0 ± 1.6 mmol·l ⁻¹ 70-79: 8.2 ± 2.0 mmol·l ⁻¹ Female La_{peak} : 40-49: 10.8 ± 2.8 mmol·l ⁻¹ 50-59: 10.3 ± 2.0 mmol·l ⁻¹ 60-69: 10.3 ± 1.9 mmol·l ⁻¹ 70-79: 8.9 ± 3.2 mmol·l ⁻¹
Zamparo et al. (2012b)	Cross-sectional	Analyze the determinants of performance in masters swimmers	Masters swimmers with masters world record (25-89 yrs old)	Assessment of the metabolic power required in swimming races and the metabolic power available	Masters swimmers' performance declined due to the decrease in metabolic power available and increase in energy cost.
Mejias et al. (2014)	Cross-sectional	Identify the energetics variables related to young masters and elite performance	8 young masters swimmers (29.75 ± 3.80 yrs old) 12 elite swimmers (20.41 ± 3.20 yrs old)	7x200 m freestyle swim	Elite swimmers presented a better performance and a higher v_d , VO_{2max} , and E_{rot} than masters swimmers. Elite and masters performance was associated with v_d

Biomechanics

Table 2 presents a summary of the six studies that have monitored the biomechanical profile in masters swimmers. The overall quality scores ranged between 10 and 13 points, representing a mean of 11.5 points.

All the studies found related with the biomechanics profile in masters swimmers were, again, cross-sectional studies. Interventions aimed to assess velocity (v) (Favaro and Lima, 2005; Gatta *et al.*, 2006; Zamparo, 2006; Zamparo *et al.*, 2012a, 2014), SF (Favaro and Lima, 2005; Gatta *et al.*, 2006; Zamparo, 2006; Zamparo *et al.*, 2012a, 2014), SL (Favaro and Lima, 2005; Gatta *et al.*, 2006; Zamparo, 2006; Zamparo *et al.*, 2012a, 2014), SI (Favaro and Lima, 2005), and η_p (Zamparo, 2006; Zamparo *et al.*, 2012a, 2014).

The comparison of v obtained in the first five analyzed studies showed that the values ranged between $0.93 \pm 0.10 \text{ m} \cdot \text{s}^{-1}$ (Zamparo *et al.*, 2012a) and $1.47 \pm 0.27 \text{ m} \cdot \text{s}^{-1}$ (Favaro and Lima, 2005). SF ranged between $0.41 \pm 0.06 \text{ Hz}$ (Zamparo *et al.*, 2012b) and $0.93 \pm 0.09 \text{ Hz}$ (Favaro and Lima, 2005). SL ranged between $1.57 \pm 0.14 \text{ m}$ (Favaro and Lima, 2005) and $2.27 \pm 0.25 \text{ m}$ (Zamparo *et al.*, 2012a). η_p ranged between 0.30 ± 0.05 (Zamparo *et al.*, 2014) and 0.36 ± 0.08 (Zamparo, 2006). Finally, it was reported that elite swimmers presented higher values of v , SF and SI than masters swimmers (Mejias *et al.*, 2014).

Favaro *et al.* (2005) reported that the biomechanics parameters (SL , SF) were influenced by age, as the older swimmers presented lower values of SL , SF and SI . Thus, the SF decreased 21.3% from the youngest (+25 years old) to the oldest age-group (+75 years old); the SL decreased 26.7% from the youngest (+25 years old) to the oldest age-group (+75 years old); the SI decreased 56.3% from the youngest (+25 years old) to the oldest age-group (+75 years old). Zamparo (2006) reported that, in male swimmers, the SF increased 1.8% from the age-group 15.8 ± 0.8 years old to the oldest age-group (54.3 ± 4.9 years old); the SL and η_p decreased, respectively, 33.5% and 37.5% from the youngest to the oldest age-group. In female swimmers, the SF decreased 15.6% from the age-group 15.5 ± 1.0 years old to the oldest age-group (45.2 ± 4.8 years old); the SL and η_p decreased, respectively, 31.2% and 28.6% from the youngest to the oldest age-group. Finally, Zamparo *et al.*, (2012b) reported that the SF increased 2.4% from the M30-40 years old age-group to the M70-80 years old age-group; the SL and η_p decreased, respectively, 30.4% and 32.3% from the youngest to the oldest age-group.

Performance

Table 3 summarizes the eight studies that analyze the performance variation in master swimmers. All the studies were cross-sectional and the overall quality scores ranged between 9 and 13 points, representing a mean of 10.8 points.

The performance of the short-duration events (50 m) ranged between 28.08 ± 2.17 s (age-group +25 years old) and 51.34 ± 13.52 s (age-group +75 yrs old) (Favaro and Lima, 2005). The performance of 100 m event ranged between 59.6 s (age-group 25-35 years old) and 96.7 s (age-group 36-55 years old) (Reaburn and Mackinnon, 1990). Regarding 200-m events, the performance time ranged between 112.84 s (Zamparo et al., 2012b) and 204.4 ± 24.9 s (Zamparo et al., 2014).

Table 2. Summary of the studies about the biomechanics of masters swimmers

Authors	Research design	Aim	Subjects	Procedures and outcomes	Findings
Favaro et al. (2005)	Cross-sectional	Verify the relationship between stroke index and performance, and stroke index and age of the swimmers over fifties	60 male swimmers: +25 yrs old: 26.78±1.56 yrs old; +30 yrs old: 31.8±1.47 yrs old; +35 yrs old: 36.8±0.84 yrs old; +40 yrs old: 42.13±1.3 yrs old; +45 yrs old: 46.5±1.46 yrs old; +55 yrs old: 56.86±1.46 yrs old; +75 yrs old: 76.50±1.38 yrs old	Swim 50 m in a Masters Swimming Tour	SR and SL were influenced by aging. SI can be used for the prediction 50 m performance of freestyle above 50 years
Zamparo (2006)	Cross-sectional	Determine the effect of age and gender on propelling efficiency (η_p)	32 males: M11: 11.3±1.7 yrs old; M14: 13.8±0.5 yrs old; M16: 15.8±0.5 yrs old; M23: 22.7±2.8 yrs old; M37: 36.8±4.8 yrs old; M54: 54.3±4.9 yrs old 31 females: F10: 9.8±0.5 yrs old; F12: 12.2±0.4 yrs old; F16: 15.5±1.0 yrs old; F23: 22.7±2.7 yrs old; F33: 33.0±2.6 yrs old; F45: 45.2±4.8 yrs old	Swim 50 m at constant velocity and stroke rate and repeat the swim at three to four incremental speeds (in a 50 m swimming pool)	η_p decreased with age. M11: 0.32±0.04 M14: 0.36±0.03 M16: 0.40±0.04 M23: 0.38±0.06 M37: 0.36±0.08 M54: 0.25±0.04 F10: 0.30±0.04 F12: 0.35±0.04 F16: 0.35±0.03 F23: 0.38±0.04 F33: 0.36±0.03 F45: 0.25±0.03
Gatta et al. (2006)	Cross-sectional	Measure v , SL and SL during the 200 m freestyle event and analyze the rate and magnitude of their age-associated declines	162 male swimmers (50-90 years): 50-54 yrs old; 55-59 yrs old; 60-64 yrs old; 65-69 yrs old; 70-74 yrs old; 75-79 yrs old; ≥80 yrs old	200 m freestyle event in Master World Championship; video-recorded for measurement of the stroke parameters	Ageing process affects SF more than SL
Zamparo et al. (2012a)	Cross-sectional	Measure the energy cost of swimming (C), the propelling efficiency of the arm stroke (η_p) and projected frontal area (A_{eff}) at submaximal aerobic speed	47 male masters swimmers: M30-40 (36.3±3.0 yrs old); M40-50 (45.8±3.1 yrs old); M50-60 (52.9±2.6 yrs old); M60-70 (62.8±1.8 yrs old); M70-80 (74.1±5.7 yrs old)	Swim at a constant submaximal, aerobic speed and a constant stroke rate for about 4 minutes (in a 25 m swimming pool)	SF (Hz) / SL (m) / η_p M30-40: 0.41 Hz / 2.27 m / 0.34 M40-50: 0.47 Hz / 2.10 m / 0.32 M50-60: 0.46 Hz / 1.86 m / 0.28 M60-70: 0.44 Hz / 1.47 m / 0.22 M70-80: 0.42 Hz / 1.58 m / 0.23
Zamparo et al. (2014)	Cross-sectional	Explore the relation between arms-only propelling efficiency, and swimming speed; and between mechanical power output and swimming speed	21 male - 33.5±9.1 yrs old; 8 female - 28.5±8.6 yrs old	200 m maximal swim trial with a pull-buoy (arms only) in a 25 m swimming pool	Maximal speed depends on η_p and on maximal power output
Mejia et al. (2014)	Cross-sectional	Identify the kinematics and efficiency variables related to young masters' performance	8 young masters swimmers (29.75±3.80 yrs old); 12 elite swimmers (20.41±3.20 yrs old)	7x200 m freestyle swim	Elite swimmers presented a higher SF, and SI than master swimmers

Table 3. Summary of the studies about the performance of masters swimmers

Authors	Research design	Aim	Subjects	Procedures and outcomes	Findings
Reaburn and Mackinnon (1990)	Cross-sectional	Determine the effect of age on maximal blood lactate concentration, time to reach maximal blood lactate concentration and half recovery time to baseline lactate concentration	16 males competitive masters swimmers divided in four age groups: 25-35: 31.3 yrs old 36-45: 41.0 yrs old 46-55: 49.5 yrs old >56: 67.0 yrs old	Maximal 100 m freestyle	Time to performed 100-m: Age-group 25-35 yrs old: 59.6 s Age-group 36-45 yrs old: 65.9 s Age-group 46-55 yrs old: 71.7 s Age-group >56 yrs old: 96.7 s
Favaro et al. (2005)	Cross-sectional	Verify the relationship between stroke index and performance, and stroke index and age of the swimmers over fifties.	60 male swimmers (25-78 years) +25 yrs old: 26.78±1.56 yrs old +30 yrs old: 316.8±1.47 yrs old +35 yrs old: 36.8±0.84 yrs old +40 yrs old: 42.13±1.3 yrs old +45 yrs old: 46.5±1.46 yrs old +55 yrs old: 56.86±1.46 yrs old +75 yrs old: 76.50±1.38 yrs old	Swim 50 m in a Masters Swimming Tour	Time to performed 50 m freestyle: Age-group +25 yrs old: 28.08±2.17 s Age-group +30 yrs old: 28.57±1.84 s Age-group +35 yrs old: 34.95±6.24 s Age-group +40 yrs old: 31.43±3.06 s Age-group +45 yrs old: 32.02±2.62 s Age-group +55 yrs old: 37.95±6.42 s Age-group +75 yrs old: 51.34±13.52 s
Zamparo et al. (2012b)	Cross-sectional	Analyze the determinants of performance in master swimmers	Masters swimmers with masters world record (25-89 yrs old)	Analyze master world records for each swimming style and each masters group of age	Time to performed 200-m freestyle: Age-group 25-29 yrs old: 112.17 s Age-group 30-34 yrs old: 113.15 s Age-group 35-39 yrs old: 112.84 s Age-group 40-44 yrs old: 113.65 s Age-group 45-49 yrs old: 117.89 s Age-group 50-54 yrs old: 120.34 s Age-group 55-59 yrs old: 124.01 s Age-group 60-64 yrs old: 132.57 s Age-group 65-69 yrs old: 138.53 s Age-group 70-74 yrs old: 146.20 s Age-group 75-79 yrs old: 145.66 s Age-group 80-84 yrs old: 173.74 s Age-group 85-89 yrs old: 193.78 s
Zamparo et al. (2014)	Cross-sectional	Explore the relation between arms-only propelling efficiency, and swimming speed; and between mechanical power output and swimming speed.	29 masters swimmers 21 male - 33.5±9.1 yrs old 8 female - 28.5±8.6 yrs old	200 m maximal swim trial with a pull-buoy (arms only) in a 25 m swimming pool	Time to performed 200-m: Male - 187.8±32.7 s Female - 204.4±24.9 s

Table 4 summarizes the eleven studies that reported the effects of age on performance. Nine of them were cross-sectional studies (Bongard *et al.*, 2007; Favaro and Lima, 2005; Gatta *et al.*, 2006; Mejias *et al.*, 2014; Ransdell *et al.*, 2009; Reaburn and Mackinnon, 1990; Tanaka and Seals, 1997; Zamparo *et al.*, 2012b, 2014) and the remaining two were longitudinal studies (Donato *et al.*, 2003; Rubin *et al.*, 2013). The overall quality scores ranged between 7 and 13 points, representing a mean of 9.9 points.

All studies that analyzed the effect of age on swimming performance (Table 2) found that performance declined with age (Bongard *et al.*, 2007; Donato *et al.*, 2003; Favaro and Lima, 2005; Mejias *et al.*, 2014; Ransdell *et al.*, 2009; Reaburn and Mackinnon, 1990; Rubin *et al.*, 2013; Tanaka and Seals, 1997; Zamparo *et al.*, 2012b). Zamparo *et al.* (Zamparo *et al.*, 2012b) found a decrease in performance as a function of age with the swimming performance time increasing 72.8 % from the younger age group 25-29 years old to the age-group 85-89 years old (25-29 years old: 112.17 s; 30-34 years old: 113.15 s; 35-39 years old: 112.84 s; 40-44 years old: 113.65 s; 45-49 years old: 117.89 s; 50-54 years old: 120.34 s; 55-59 years old: 124.01 s; 60-64 years old: 132.57 s; 65-69 years old: 138.53 s; 70-74 years old: 146.20 s; 75-79 years old: 145.66 s; 80-84 years old: 173.74 s; 85-89 years old: 193.78 s). A progressive increase in 100 m swimming time was found with increasing age (Reaburn and Mackinnon, 1990): 25-35 years old: 59.6 s; 36-45 years old: 65.9 s; 36-55 years old: 71.7 s; > 56 years old: 96.7 s. In this study (Reaburn and Mackinnon, 1990), the swimming time performance increased 62.2% from the age-group 25-35 years old to the swimmers older than 56 years old. One of the studies compared elite with master swimmers (Mejias *et al.*, 2014) and reported that the first presented a better performance than master swimmers. Bongard *et al.* (Bongard *et al.*, 2007) analyzed the distance traveled by men and women, of different ages, over one hour of swimming. The results reveal a significant decrease in swimming distances from the youngest to the oldest age-group in both genders: in men the swimming distance decreased 84.7% whereas in women decreased 105.5%. Other study found that the 200 m performance declined 9-14% between the ages of 35 and 45 years (Ransdell *et al.*, 2009). A longitudinal study over a period of 12 years old (Donato *et al.*, 2003) reported that the long and short duration swimming performance (1500 m and 50 m, respectively) declined with age. However, the rate of decline in swimming performance with age was greater in a long-duration (6 to 12%) than in a short-duration event (3 to 8%). In this study, the peak of performance in the 1500 m event was maintained until about 35 years old, followed by a progressive decrease until about 70 years old. Rubin *et al.* (Rubin *et al.*, 2013) reported that, in men, performance decline in the 50 m (0.34%-0.55% per year), 100 m (0.26%-0.68% per year), and 1500 m (0.13%-0.55% per year). The same study (Rubin *et al.*, 2013) also reported that, in women, performance decrease in the 50 m (0.13%-0.93% per year), 100 m (0.10%-1.2%), and in 1500 m (0.04%-0.94% per year). Other study indicated that in the 50 m event, the decrease in performance was smaller compared with the 1500 m event (Donato *et al.*,

2003). The 50 m performance was influenced by aging (Favaro and Lima, 2005) with the swimming performance time increasing 82.3% from the younger (+25 years old) to the oldest age-group (+75 years old): +25 yrs old: 28.08±2.17 s; +30 yrs old: 28.57±1.84 s; +35 yrs old: 34.95±6.24 s; +40 yrs old: 31.43±3.06 s; +45 yrs old: 32.02±2.62 s; +55 yrs old: 37.95±6.42 s; +75 yrs old: 51.34±13.52 s. Tanaka and Seals (Tanaka and Seals, 1997) reported that after 35 and 40 years of age swimming performance declined until 70 years of age in women and men, respectively. In long-duration events (1500 m), the swimming performance time increased 31.7% and 38.7% in men and women, respectively, whereas in short-duration events (50 m) performance time increased 26.7% in men and 31.7% in women (Tanaka and Seals, 1997).

Table 4. Summary of the studies about the effect of age on performance of masters swimmers

Authors	Research design	Aim	Subjects	Procedures and outcomes	Findings
Reaburn and Mackinnon (1990)	Cross-sectional	Determine the effect of age on: maximal blood lactate concentration, time to reach maximal blood lactate concentration and half recovery time to baseline lactate concentration	16 males competitive masters swimmers divided in four age groups: 25-35: 31.3 yrs old 36-45: 41.0 yrs old 46-55: 49.5 yrs old >56: 67.0 yrs old	Maximal 100 m freestyle	Increase in best recorded 100-m swimming time was observed with increasing age Age-group 25-35 yrs old: 59.6 s Age-group: 36-45 yrs old: 65.9 s Age-group 46-55 yrs old: 71.7 s Age-group >56 yrs old: 96.7 s
Tanaka and Seals (1997)	Cross-sectional	Determine the effect of age on performance in adult men and women	Participants in US Masters Swimming Championships (19-99 yrs old)	Retrospective analysis of top US Masters freestyle times	Endurance swimming performance decrease with age in men and women After 35 and 40 years of age swimming performance declined until 70 years of age in women and men, respectively
Donato et al. (2003)	Longitudinal	Analyze the relationship among age, gender, and endurance swimming performance	319 men and 321 women 19-85 yrs old	Analysis of freestyle performance times from the US MS Championships over a 12years period of 1988-1999	Declines in swimming performance with age were greater in long-duration (6 to 12%) than in short-duration (3 to 8%) events.
Favaro et al. (2005)	Cross-sectional	Verify the relationship between stroke index and performance, and stroke index and age of the swimmers over fifties	60 male swimmers (25-78 years) +25 yrs old: 26.78±1.56 yrs old; +30 yrs old: 316.8±1.47 yrs old; +35 yrs old: 36.8±0.84 yrs old; +40 yrs old: 42.13±1.3 yrs old; +45 yrs old: 46.5±1.46 yrs old; +55 yrs old: 56.86±1.46 yrs old; +75 yrs old: 76.50±1.38 yrs old	Swim 50 m in a Masters Swimming Tour	50 m performance was influenced by aging +25 yrs old: 28.08±2.17 s +30 yrs old: 28.57±1.84 s +35 yrs old: 34.95±6.24 s +40 yrs old: 31.43±3.06 s +45 yrs old: 32.02±2.62 s +55 yrs old: 37.95±6.42 s +75 yrs old: 51.34±13.52 s
Zamparo (2006)]	Cross-sectional	Examine the effects of age and gender on performance	4271 healthy men and women aged 19-91 years Men - 45.2±13.0 yrs old Women - 41.7±13.1 yrs old	One hour swimming (2001-2003)	From the youngest decade (19-29 yrs) to the oldest (≥80 yrs) the decline in mean performance was 45.9% for men and 51.3% for women
Mejia et al. (2014)	Cross-sectional	Identify the energetics variables related to young masters' and elite performance	8 young masters swimmers (29.75±3.80 yrs old) and 12 elite swimmers (20.41±3.20 yrs old)	7x200 m freestyle swim	Elite swimmers presented a better performance than master swimmers

Table 4. Summary of the studies about the effect of age on performance of masters swimmers (cont.)

Authors	Research design	Aim	Subjects	Procedures and outcomes	Findings
Ransdell et al. (2009)	Cross-sectional	Examine age and gender differences in world-record performances of master athletes in swimming	Men and women masters' swimmers (35-50 yrs old)	Examine masters' world record times in a 25 m pool, for freestyle stroke in 100m, 200m, 400, 800m and 1500m distances	200 m world record in men /women: 35 yrs old: 1.87 minutes / 2.07 minutes 40 yrs old: 1.83 minutes / 2.08 minutes 45 yrs old: 1.92 minutes / 2.10 minutes 50 yrs old: 1.97 minutes / 2.25 minutes 55 yrs old: 2.06 minutes / 2.25 minutes 60 yrs old: 2.17 minutes / 2.63 minutes 65 yrs old: 2.27 minutes / 2.70 minutes 70 yrs old: 2.42 minutes / 2.75 minutes 75 yrs old: 2.47 minutes / 2.95 minutes 80 yrs old: 2.98 minutes / 3.32 minutes 85 yrs old: 3.22 minutes / 3.90 minutes 90 yrs old: 3.67 minutes / 4.42 minutes
Zamparo et al. (2012b)	Cross-sectional	Analyze the determinants of performance in master swimmers	Masters swimmers with masters world record (25-89 yrs old)	Analyze master world records for each swimming style and each master's group of age	Time to performed 200-m freestyle: Age-group 25-29 yrs old: 112.17 s Age-group 30-34 yrs old: 113.15 s Age-group 35-39 yrs old: 112.84 s Age-group 40-44 yrs old: 113.65 s Age-group 45-49 yrs old: 117.89 s Age-group 50-54 yrs old: 120.34 s Age-group 55-59 yrs old: 124.01 s Age-group 60-64 yrs old: 132.57 s Age-group 65-69 yrs old: 138.53 s Age-group 70-74 yrs old: 146.20 s Age-group 75-79 yrs old: 145.66 s Age-group 80-84 yrs old: 173.74 s Age-group 85-89 yrs old: 193.78 s
Rubin et al. (2013)	Longitudinal	Examine individual swimmers' data across an average of 23 years	19 male and 26 female masters swimmers (minimum age of 25 yrs old)	Analyze the results obtained by elite swimmers who participated in competitions for an average of 23 years from US Masters Swimming and the International Masters Swimming Hall of Fame	50 m performance decline with age in men (0.34%-0.55% per year) and women (0.13%-0.93% per year) 100 m performance decline with age in men (0.26%-0.68% per year) and women (0.10%-1.2% per year) 1500 m performance decline with age in men (0.13%-0.55% per year) and women (0.04%-0.94% per year)

Gender gap

Table 5 presents the two studies that aimed to analyze the difference between gender in post-competition blood lactate concentration (Benelli *et al.*, 2007); and in VO_{2max} in a maximal incremental test on a modified arm-crank-ergometer (Zamparo *et al.*, 2014). The overall quality scores of both studies were 13 points, representing a mean score of 13 points.

Comparing genders, male presented higher La_{peak} than female: $14.2 \pm 2.5 \text{ mmol}^{-1}$ vs. $10.8 \pm 2.5 \text{ mmol}^{-1}$ (Benelli *et al.*, 2007). VO_{2max} was larger in male than in female swimmers: $33.1 \pm 4.6 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ and $27.2 \pm 4.2 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$, respectively (Zamparo *et al.*, 2014).

In Table 6, both studies related to the biomechanics gender gap (Zamparo, 2006; Zamparo *et al.*, 2014) reported the absence of significant differences between both groups in SF , SL and η_p . In Zamparo's study (Zamparo, 2006), v was significantly higher in male compared to female: $1.29 \pm 0.19 \text{ m} \cdot \text{s}^{-1}$ vs. $1.17 \pm 0.10 \text{ m} \cdot \text{s}^{-1}$. However, Zamparo *et al.* (2014) reported no significant difference in v_{200} between male and female swimmers. The overall quality scores ranged between 11 and 13 points, representing a mean of 12 points.

Table 7 presents the studies that aimed to analyze the difference between genders in performance (Bongard *et al.*, 2007; Donato *et al.*, 2003; Ransdell *et al.*, 2009; Rubin *et al.*, 2013; Rüst *et al.*, 2012; Tanaka and Seals, 1997; Zamparo *et al.*, 2014). Comparing performance between genders, Bongard *et al.* (2007) reported that in longer distances (one hour swimming) there was no gender difference in performance. This idea may be complemented by the data reported by Tanaka and Seals (1997). According to these authors, the gender differences in swimming performance were greatest in short-duration events and performance time differences became smaller as swim distance increased (Tanaka and Seals, 1997). Ransdell *et al.* (2009) and Rüst *et al.* (2012) reported that, in 200 m distance, men presented a better performance than women, 10.7% and $10.8 \pm 0.9\%$, respectively. Contrariwise, a non-significant difference in 200 m performance between male and female swimmers was found (Zamparo *et al.*, 2014). The overall quality scores ranged between 7 and 13 points, representing a mean of 10.5 points.

Table 5. Summary of the studies about the energetic gender gap of masters swimmers

Authors	Research design	Aim	Subjects	Procedures and outcomes	Findings
Benelli et al. (2007)	Cross-sectional	Measure the post-competition blood lactate concentration (LA_{peak}) in masters swimmers of both genders aged between 40-79 years and to relate it to age and swimming performance	108 masters swimmers 56 females (40-49: 44.1±3.6 yrs old; 50-59: 53.9±2.7 yrs old; 60-69: 64.6±3.0 yrs old; 70-79: 73.1±2.6 yrs old) 52 males (40-49: 44.2±2.5 yrs old; 50-59: 54.6±3.2 yrs old; 60-69: 64.8±3.1 yrs old; 70-79: 73.0±2.5 yrs old)	1 testing occasion 5 minutes after race participating in the 10 th World Master Championship in 2004	Male exhibited higher LA_{peak} than women in all the age groups Male 40-49: 14.2±2.5 mmol·l ⁻¹ 50-59: 12.4±2.5 mmol·l ⁻¹ 60-69: 11.0±1.6 mmol·l ⁻¹ 70-79: 8.2±2.0 mmol·l ⁻¹ Female 40-49: 10.8±2.8 mmol·l ⁻¹ 50-59: 10.3±2.0 mmol·l ⁻¹ 60-69: 10.3±1.9 mmol·l ⁻¹ 70-79: 8.9±3.2 mmol·l ⁻¹

Table 6. Summary of the studies about the biomechanics gender gap of masters swimmers

Authors	Research design	Aim	Subjects	Procedures and outcomes	Findings
Zamparo (2006)	Cross-sectional	Determine the effect of age and gender on propelling efficiency (η_p)	32 males divided into 6 groups: M11: 11.3±1.7 yrs old; M14: 13.8±0.5 yrs old; M16: 15.8±0.5 yrs old; M23: 22.7±2.8 yrs old; M37: 36.8±4.8 yrs old; M54: 54.3±4.9 yrs old 31 females divided into 6 groups: F10: 9.8±0.5 yrs old; F12: 12.2±0.4 yrs old; F16: 15.5±1.0 yrs old; F23: 22.7±2.7 yrs old; F33: 33.0±2.6 yrs old; F45: 45.2±4.8 yrs old	Swim 50 m at constant velocity and stroke rate and repeat the swim at three to four incremental speeds (in a 50 m swimming pool)	η_p was almost the same in male and female swimmers of the same age group and swimming ability M11: 0.32±0.04 M14: 0.36±0.03 M16: 0.40±0.04 M23: 0.38±0.06 M37: 0.36±0.08 M54: 0.25±0.04 F10: 0.30±0.04 F12: 0.35±0.04 F16: 0.35±0.03 F23: 0.38±0.04 F33: 0.36±0.03 F45: 0.25±0.03
Zamparo et al. (2014)	Cross-sectional	Explore the relation between arms-only propelling efficiency, and swimming speed; and between mechanical power output and swimming speed	29 masters swimmers 21 male - 33.5±9.1 yrs old 8 female - 28.5±8.6 yrs old	200 m maximal swim trial with a pull-buoy (arms only) in a 25 m swimming pool	No significant differences were found in SF , SL and η_p between male and female swimmers

Table 7. Summary of the studies about the performance gender gap of masters swimmers

Authors	Research design	Aim	Subjects	Procedures and outcomes	Findings
Tanaka and Seals (1997)	Cross-sectional	Determine the effect of age on performance in adult men and women	Participants in US Masters Swimming Championships (19-99 yrs old)	Retrospective analysis of top US Masters freestyle times	The magnitude of declines in swimming performance with age was greater in women than in men Gender differences in swimming performance were greatest in short duration events and least in endurance events
Donato et al. (2003)	Longitudinal	Analyze the relationship among age, gender, and endurance swimming performance	319 men and 321 women 19-85 yrs old	Analysis of freestyle performance times from the US MS Championships over a 12years period of 1988-1999	Female swimmers experience greater declines in sprint swimming performance than male
Bongard et al. (2007)	Cross-sectional	Examine the effects of age and gender on performance	4271 healthy men and women aged 19-91 years Men - 45.2±13.0 yrs old Women - 41.7±13.1 yrs old	One hour swimming (2001-2003)	In longer distances there was no gender difference
Ransdell et al. (2009)	Cross-sectional	Examine age and gender differences in world-record performances of master athletes in swimming	Men and women masters' swimmers (35-50 yrs old)	Examine masters world record times in a 25 m pool, for freestyle stroke in 100m, 200m, 400, 800m and 1500m distances	35 yrs old: men present a performance 10.7% better than women 40 yrs old: men present a performance 13.7% better than women 45 yrs old: men present a performance 9.3% better than women 50 yrs old: men present a performance 14.2% better than women. 55 yrs old: men present a performance 9.2% better than women 60 yrs old: men present a performance 21.2% better than women 65 yrs old: men present a performance 18.9% better than women 70 yrs old: men present a performance 13.6% better than women. 75 yrs old: men present a performance 19.4% better than women 80 yrs old: men present a performance 11.4% better than women 85 yrs old: men present a performance 21.1% better than women 90 yrs old: men present a performance 20.4% better than women

Table 7. Summary of the studies about the performance gender gap of masters swimmers (cont).

Authors	Research design	Aim	Subjects	Procedures and outcomes	Findings
Rubin et al. (2013)	Longitudinal	Examine individual swimmers' data across an average of 23 years	19 male and 26 female masters swimmers (minimum age of 25 yrs old)	Analyze the results obtained by elite swimmers who participated in competitions for an average of 23 years from US Masters Swimming and the International Masters Swimming Hall of Fame	Men were faster than women at most ages. Male and female improved their ability during the early years of participation
Rüst et al. (2012)	Longitudinal	Investigate the age range of peak freestyle swim speed Find differences in age range and peak freestyle swim speed between male and female	50.519 swimmers (24.656 women and 25.863 men) 0-9 yrs old; 10-19 yrs old; 20-29 yrs old; 30-39 yrs old; 40-49 yrs old; 50-59 yrs old; 60-69 yrs old; 70-79 yrs old	Analyze of swimming performance across age groups ranked on the Swiss swimming high score list between 2006 and 2010	Gender difference in performance was: 50-m freestyle: 13.1±1.3% 100-m freestyle: 13.2±0.9% 200-m freestyle: 10.8±0.9% 400-m freestyle: 7.9±1.3% 800-m freestyle: 4.2±2.0%
Zamparo et al. (2014)	Cross-sectional	Explore the interplay between arms-only propelling efficiency, mechanical power output and swimming speed	29 masters swimmers 21 male - 33.5±9.1 yrs old 8 female - 28.5±8.6 yrs old	200 m maximal swim trial with a pull-buoy (arms only) in a 25 m swimming pool	No significant difference was found in performance between male and female swimmers

Discussion

The purpose of this investigation was to summarize evidence shown in studies conducted on master swimmers to characterize the biomechanics and energetic profiles, and performance. We also examined the effect of gender on the biomechanics and energetic profiles, and performance. As can be seen in a first analysis, the selected studies related with energetics, biomechanics and performance in master swimmers are relatively recent, being visible the increased interest in this age group, since 2000. This increase may be due to several reasons: the aging population, the growth of the number of adults participating in organized sports, greater health concerns, and coaches are gaining increasing experience in this age-group (Rubin and Rahe, 2010). In addition, swimming is advantageous for adult subjects once it is a medically safe and non-weight bearing activity, enabling the participation of a large array of subjects, even those that may present limitations or other orthopedic injuries (Rubin et al., 2013). However, we failed to find in the literature longitudinal studies analyzing the energetics and biomechanics profiles, and/or the performance changes over time. The selected studies mainly report data about swimmers that competed at local or national level (Bongard et al., 2007; Favaro and Lima, 2005; Mejias et al., 2014; Zamparo, 2006; Zamparo et al., 2012a, 2014), and swimmers in the top of the national ranking (Benelli et al., 2007; Donato et al., 2003; Gatta et al., 2006; Ransdell et al., 2009; Reaburn and Mackinnon, 1990; Rubin et al., 2013; Rüst et al., 2012; Tanaka and Seals, 1997; Zamparo et al., 2012b). Regarding performance, there are few longitudinal studies related with the effects of aging (Donato et al., 2003; Ransdell et al., 2009; Rubin et al., 2013; Tanaka and Seals, 1997) and of gender (Rubin et al., 2013; Rüst et al., 2012; Tanaka and Seals, 1997).

4.1 Quality Assessment

The majority of the articles, included in this systematic review, presented low quality scores compared to other scientific fields. A similar low quality score (11.68 points) was also reported in 28 studies conducted with elite swimmers (Costa *et al.*, 2012a). These results suggest that, in this field, research needs to improve some important items to enhance their quality. Regarding the different domains, the higher scores obtained by the studies related to biomechanics may be due to the use of more valid and reliable procedures to measure the variables. The earlier (Reaburn and Mackinnon, 1990) and the most recent study (Mejias *et al.*, 2014) obtained 10 points while the scores of intermediate studies varied from 6 to 13 points. Thus, it seems that the publication date did not influence the quality of the studies. The checklist used here, for quality assessment, was built based on more accurate scientific areas, being focused on procedures such as randomization, blindness, and the use of control group or practical effects (Costa *et al.*, 2012a) which are hard to attain in the studies of this area. In fact, it is difficult to obtain random sampling, including subjects that would be representative for the entire population, since the number of swimmers with the specific features available for these studies is reduced. In order to minimize this limitation, convenience samples are used. Considering this, the development of a more adequate list, adjusted

to the characteristics of this field of study may be necessary or, whenever possible, swimming researchers should consider the aspects mentioned previously to improve the quality of the studies.

4.2 Energetics

La_{peak} was the energetic variable used to assess the anaerobic capacity of the swimmers. La_{peak} is thought to provide useful information on the anaerobic glycolytic activity in working muscles during supramaximal exercise (Korhonen et al., 2005). The difference found in La_{peak} values may be attributed to the differences in the test performed to measure it, such as its duration, as the contribution of the energy systems depends both on the intensity and duration of the exercise (Gastin, 2001). The contribution of the anaerobic lactic energy sources decreases along with the duration of exercise (Zamparo et al., 2011). However, in Reaburn and Mackinnon [13] and Benelli et al. (Benelli et al., 2007) the La_{peak} data found in the age-groups 25-35 years old and 40-49 years old was similar although the event was different (100-m vs. 200-m). The fact that may justify the high value found by Benelli et al. (Benelli et al., 2007) is that the data collection was carried during the world championship where the motivation for reaching the best performance was higher. The decrease of La_{peak} with the advancing of age may be explained by the decrease of the maximal anaerobic power in the oldest subjects (Zamparo et al., 2012b). This decrease in anaerobic performance may be attributed to changes in morphological factors (decreased muscle mass and type II muscle fiber atrophy), muscle contractile property (decreased rate of force development) and biomechanical aspects (changes in enzyme activity and decreased lactate production) arising from ageing (Reaburn and Dascombe, 2009).

Finally, the higher values of v_4 , VO_{2max} and total energy expenditure (E_{tot}) presented by the elite swimmers compared to masters may be explained by the characteristics of the training carried out by masters swimmers, as the lower volume of training and training loads, predominantly aerobic, will not be enough to improve the energy production systems (Mejias et al., 2014). Moreover, the commitment of masters swimmers with training is quite different from the one of elite swimmers, due to different goals and professional/familiar compromises.

The quality of life, cardiovascular disease, all-cause mortality, and the ability to perform the tasks of the daily life and the ease with which these tasks can be performed (i.e., physiological functional capacity) depend largely on the maintenance of sufficient aerobic capacity and strength (Fleg et al., 2005) and the most frequently used measure of physiological functional capacity is VO_{2max} (Tanaka and Seals, 1997). It is commonly accepted that physical activity increases VO_{2max} (Coyle, 1995), as evidenced by the data reported in several studies that VO_{2max} of active and athletic subjects was significantly greater than sedentary subjects of similar age (Eskurza et al., 2002; Fitzgerald et al., 1997; Katznel et al., 2001; Ogawa et al., 1992; Weiss et al., 2006). However, the role of exercise on the age-associated decline of VO_{2max} is highly controversial (Fleg et al., 2005). Several studies reported a rate of decline of 10% per decade after the age of 25 years-old in healthy sedentary individuals (Buskirk and Hodgson, 1987; Eskurza et al., 2002; Fitzgerald et al., 1997; Tanaka and Seals, 1997). Moreover, it has been proposed that continued exercise training may slow

the rate of decline of VO_{2max} at a rate of 5% per decade rather than the 10% per decade mentioned earlier (Bortz IV and Bortz II, 1996; Hagberg, 1987). On the contrary, some studies reported that the rate of decline of VO_{2max} was similar in athletic and sedentary subjects (Katzel et al., 2001; Tanaka et al., 1997). Although, it was expected that age per se would contribute to the decline of VO_{2max} , it appears that the decrease in the practice of regular aerobic exercise may result in a higher rate of decline that could result in a loss of independence in carrying out daily tasks. Thus, it is important to maintain a vigorous physical activity to mitigate the age-related decrease in VO_{2max} (Fleg et al., 2005; Hawkins and Wiswell, 2003). For all the reasons mentioned earlier, VO_{2max} is considered a good health indicator, once the decrease in maximal aerobic capacity with age has a number of physiological and clinical implications such as increased risks for cardiovascular and all-cause mortality, disability, and reductions in cognitive function, quality of life, and independence (Eskurza et al., 2002; Fitzgerald et al., 1997). Considering this, Bongard et al (Bongard et al., 2007) suggested that masters swimmers have a lower cardiovascular risk than their less physically active counterparts.

4.3 Biomechanics

The biomechanical changes within a season are important, to analyze the effectiveness of the stroke mechanics, whereby SF , SL , SI and η_p have been described as variables to assess the swimming technique. The analysis of the six studies showed that the studies of Favaro et al. (Favaro and Lima, 2005) and Zamparo et al. (Zamparo et al., 2012a) obtained the outliers values of SF and SL . One reason may be the different protocol used in each study (time trial or official race), including the selected distance and intensity. Regarding SF , the reason for the higher value found by Favaro et al. (Favaro and Lima, 2005) was the shorter distance performed (50 m) and the context in which the test was conducted (official competition). In short-distances, v increases at the expense of the increase of SF and not of SL while at submaximal velocity, v is achieved by a smaller SF and a larger SL (Zamparo et al., 2012a). The higher value of SL reported by Zamparo et al. (Zamparo et al., 2012a) may be attributed to the test performed (swim for four minutes at a constant submaximal speed) and, consequently, to the v reached in the test, once SL increases with distance increase, being larger at slow swimming speeds and tends to decrease at maximal speed. Finally, the lower η_p obtained by Zamparo et al. (Zamparo et al., 2014) may be explained by the intensity of the effort performed. Thus, in this study, the swimmers performed 200 m at a maximal velocity while the data of Zamparo (Zamparo, 2006) was obtained at a submaximal and constant velocity. η_p is proportional to the distance covered per stroke and tends to decrease at high speeds (Zamparo, 2006). The lower v , SF , and SI found in masters compared to elite swimmers may be explained by the lower mechanical power and muscle strength of the former (Mejias et al., 2014). Favaro et al. (Favaro and Lima, 2005) reported that the biomechanics parameters (SL , SF) were influenced by age, as the older swimmers presented lower values of SL , SF and SI . The SL and SF depend on muscle strength and the ability to exert powerful and effective stroke in water and, as

we earlier mentioned, with the advancing of age occurs a decrease in the muscle mass and the type II muscle fibers atrophy.

4.4 Performance

Considering 200-m events, the results mentioned previously showed differences in the time required to perform 200-m which was due the environment and type of test performed. Thus, the best performance (Zamparo et al., 2012b) represents the 200-m freestyle master world record, reached in a competition event, while the worst time was obtained in a test where only arms were used to swim (Zamparo et al., 2014).

All the studies related with performance reported the decline of swimming performance with advancing of age (i.e. performance time increases). The power and capacity of the immediate (ATP-PCr), short-term (anaerobic glycolysis), and long-term (oxidative phosphorylation) systems of energy production are the major factors in determining swimming performance (Toussaint and Hollander, 1994). With the advancing of age, we found a decrease in the aerobic and anaerobic contributors and/or an increase in energy cost (Rubin et al., 2013; Zamparo et al., 2012b). As earlier mentioned (section 4.2), cross-sectional and longitudinal studies investigated the changes in maximal aerobic power (VO_{2max}) occurred as a function of age. The cross-sectional studies indicated that VO_{2max} decreased about 10% per decade, after the third decade of life, in both genders, regardless of the activity level, whereas the longitudinal studies reported a similar trend, though with a larger variance depending on the level of training. Maximal anaerobic power also decreases with age (Zamparo et al., 2012b). Although this consensual decrease in aerobic and anaerobic found, it seems that the rate of the decline in swimming performance with age was greater in long-duration than short-duration events which could mean that physiological determinants of short and long-duration performance decrease at different rates with advancing age. Thus, it was suggested that maximal aerobic capacity exhibits a considerably higher rapid rate of decline with age than the anaerobic power (Donato et al., 2003). However, despite be slower, the decline of anaerobic power also occurs due to the decreased muscle mass and type II muscle fiber atrophy, decreased rate of force development and changes in enzyme activity and decreased lactate production (Reaburn and Dascombe, 2009).

Regarding energy cost, its increase with age is due either to an increase of hydrodynamic resistance, due morphological characteristics changes in body size and density, fat distribution, and skin stiffness, or to a decrease of propelling efficiency and overall efficiency (Zamparo et al., 2012a). The latter depend on the technical skill of the swimmers (Termin and Pendergast, 2000). Considering this, it is important to remember that some of the swimmers who participated in the studies were not swimmers in their youth, starting to swim only in adults, so the lower technical level is expected.

In addition to the physiological factors, the decline in performance was also due to sociological changes that occur with age, such as professional and familiar responsibilities that do not allow a major commitment.

4.5 Gender gap

Comparing genders, La_{peak} was higher in males compared to females which may be related to the greater rates of type II fiber atrophy (Macaluso and Vito, 2004) exhibited by women. The type II fiber uses anaerobic metabolic processes to generate ATP, enabling short contraction time and the ability to produce high tension (Favaro and Lima, 2005). Therefore, it is expected that female swimmers muscles lose their ability for power strength as a result of the preferential fibers atrophy (Macaluso and Vito, 2004). Apart from the proportion of fast-twitch fibers, the post-exercise lactate concentration depends also on the total muscle mass involved in the activity (Jensen-Urstad et al., 1994), and considering that men have a greater skeletal muscle mass than women (Janssen et al., 2000), the higher La_{peak} value presented by male swimmers was expected.

Regarding gender differences, the two included studies (Zamparo, 2006; Zamparo et al., 2014) reported no significant differences in SF , SL and η_p between male and female swimmers which may be due to the anthropometric characteristics and performance level of the swimmers.

In Zamparo's study (Zamparo, 2006), v was significantly higher in male compared to women: $1.29 \pm 0.19 \text{ m}\cdot\text{s}^{-1}$ vs. $1.17 \pm 0.10 \text{ m}\cdot\text{s}^{-1}$. v depends on the interplay between biomechanical (SF , SL , and η_p) and energetic aspects (aerobic + anaerobic) and is determined by the energy cost of swimming and the metabolic power the swimmer can generate (Pendergast and Zamparo, 2011). As mentioned in the previous paragraph, the biomechanics parameters were similar in both genders, whereby the higher v , in this case, may be dependent on the maximal aerobic-anaerobic power of the subjects (Zamparo et al., 2000). It was reported that anaerobic performance of elite male masters athletes was 10-20% better than that of elite female of the same age (Donato et al., 2003; Tanaka and Seals, 1997), which may be related with the smaller fiber cross-sectional areas of the muscle presented by women (Jaworowski et al., 2002). This mean that, in men, the larger relative area of muscle is composed of type II fibers and this may justify the different metabolic capacity of the muscles (Jaworowski et al., 2002). Moreover, men's muscle possess significantly higher activities in anaerobic enzymes, such as phosphofructokinase (PFK) and lactate dehydrogenase (LDH) when compared to women (Jaworowski et al., 2002). Regarding aerobic capacity, it was suggested that women also have lower values of VO_{2max} (15-30%) than male counterparts, specially due to (Coyle, 1995): i) smaller heart size; ii) lower hemoglobin concentration; and iii) lower blood oxygen carrying capacity. As such, men tend to have higher anaerobic and aerobic capacities than women, which may support the differences in v .

The literature research showed that the gender gap in swimming performance was wider in short-duration events, and the difference in the performance times became narrow as swim distance increased. In short-duration effort, the major contributor to the energy production is the anaerobic metabolism and the fact that women exhibited greater rates of type II fiber atrophy (Macaluso and

Vito, 2004) and lower peak blood lactate concentration following anaerobic performance (Benelli et al., 2007) may be the reasons for the differences found in short-duration events. Moreover, women appear to experience greater declines in muscular strength and power (essential determinant of sprint performance) than men (Porter et al., 1995) likely due to the smaller mean type II fiber areas found compared to men (Aniansson et al., 1981). The type II fiber uses anaerobic metabolic processes to generate ATP, enabling short contraction time and the ability to produce high tension (Reaburn and Mackinnon, 1990). Therefore, it is expected that female swimmers impair its ability to produce power strength as a result of the preferential loss of type II fibers (Macaluso and Vito, 2004) and lower anaerobic contribution. Also important is the fact that women have less lean muscle in relation to total body weight and lower total stores of ATP, PCr and glycogen than men (McGlynn, 1996).

Unlike, the absence or the smaller gender differences found in longer distances (Bongard et al., 2007; Donato et al., 2003; Tanaka and Seals, 1997) may be explained by the swimming economy, once the higher economy of swimmers contributes more to determinants of performance as the swim distance increases. Considering that, women are more economical than men due to the smaller body size and density, greater fat percent and shorter legs which result in a more horizontal and streamlined position (Lavoie and Montpetit, 1986) whereby women have a greater ability to conserve body energy stores during longer swimming events (Tanaka and Seals, 2003). Hence, it is possible that the age-associated impairment in the physiological determinants of sprint and endurance may occur at different rates in men and women (Favaro and Lima, 2005).

Ransdell et al. (Ransdell et al., 2009) and Rüst et al. (Rüst et al., 2012) reported that men presented a better performance than women in 200-m. The 200-m distance requires the energy production of both aerobic and anaerobic pathways (Costa et al., 2012b). Likely, the higher deliver from the anaerobic pathway (anaerobic lactic and alactic) presented by male compared to female (mentioned previously) may explain the better performance in this distance. The absence of significant differences in performance between gender in the study of Zamparo et al. (Zamparo et al., 2014) may be due to the heterogeneity of the sample, with swimmers having lower technical ability and swimming experience.

In summary, differences in the 200-m performance between genders may be attributed to both energetics and biomechanics factors. The main energy source for the 200-m is aerobic followed by the anaerobic lactic system, and, in both cases, men had higher values than women.

Conclusions

The only longitudinal studies found were related to the assessment of performance over time. Studies related with energetics and biomechanics parameters in masters swimmers were all cross-sectional studies. Males presented higher aerobic and anaerobic capacity than female swimmers. Physical activity is important to mitigate the age-related decreases in VO_{2max} , ensuring decreased cardiovascular disease, all-cause mortality, disability, reductions in cognitive function, increasing

the quality of life, and independence. Biomechanics parameters, SF , SL and η_p , were influenced by age (decreasing) but not by gender. In the 200-m, performance declines with age and male swimmers presented a better performance than female, although this difference tends to decrease in long-distance events.

This review shows the lack of longitudinal studies, specific for this age-group, to evaluate the changes in energetics and biomechanics factors over time, influencing performance. These data would be of utmost importance for the design of appropriate training programs for masters swimmers.

Chapter 3 - Experimental Studies

Study 2

Energetic and biomechanical contributions for longitudinal swimming performance in masters swimmers

Abstract

Background: The identification of the factors that might predict, with higher accuracy, the swimming performance is important even in masters athletes since this age-group also aims to reach the best performance.

Research question: How does performance, energetic, and biomechanics improve over a season in masters swimmers?

Type of study: A descriptive follow-up study.

Methods: Twenty three masters swimmers (34.9±7.4 years old; 2014 FINA points (286.0±121.7): twelve male (age of 35.0±7.5-y; 2014 FINA points 315.0±128.6) and eleven female (age of 34.7±7.3-y; 2014 FINA points 254.3±110.8). Swimmers were assessed in three time periods (TP) during a season. An incremental 5 × 200 m step test, in a 25 m pool, was used to evaluate the 200 m freestyle performance and their average swimming velocity (v_{200}). Velocity at 4 mmol·l⁻¹ of blood lactate concentration (v_4), maximal blood lactate concentration after exercise (La_{peak}), maximal oxygen uptake (VO_{2max}), stroke frequency (SF), stroke length (SL), stroke index (SI) and propelling efficiency of the arm stroke (η_p) were also considered.

Results: Masters performance improved through the season in agreement with a v_{200} increase between TP₁ and TP₂. Both v_4 and VO_{2max} increased throughout the season, but not La_{peak} , which remained unchanged. While SF decreased, SL , SI and η_p exhibited an increase from the beginning until the end of the season.

Conclusions: Masters swimmers improved significantly their 200 m freestyle performance over a season. In the first months of the training season, there was an improvement in the swimming technique (SL). From mid phases until the end of the season, SF also acted on performance. Each swimmer used an individual strategy, combining SF and SL , to reach higher performances

throughout the season. Although we found improvement in energetic factors throughout the season, in this age-group the performance seems to be more dependent on technical than energetic factors.

Keywords: masters, swimmers, performance, energetic profile, biomechanical profile

Introduction

Masters athletes offer a rich source of data for the determination of the rate of physical decline associated with aging in physically fit men and women (Rubin *et al.*, 2013). They strive to maintain, or even improve upon the performance achieved at younger ages, although declines in athletic performance are inevitable with ageing (Tanaka and Seals, 2008). Despite these limitations caused by age, masters athletes are a fascinating model of exceptionally successful ageing, and therefore are highly deserving of scientific attention.

The reasons beyond the participation of masters athletes in competitions and/or of being involved in regular exercise and sport are social reasons such as enjoyment, travel, stress relief and skill development like competition, physical fitness and health benefits (Tantrum and Hodge, 1993). However, the attainment of the best performance is also a goal in this age group whereby the identification of the factors that might predict, with higher accuracy, the swimming performance is, also in masters, important. Literature reports that, in young and elite swimmers, 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).

Among the biomechanical variables are the stroke frequency (*SF*), stroke length (*SL*), stroke index (*SI*) and propelling efficiency of the arm stroke (η_p). The goal of a competitive swimmer is to travel a given distance as fast as possible, whereby mean swimming velocity (v) is the best measure for swimming performance (Craig *et al.*, 1985). Swimming velocity can be described by its independent variables: *SF* and *SL*. *SF* is defined as the number of full stroke cycles performed within a unit of time, depending on muscle power. *SL* is defined as the horizontal distance that the body travels during a full stroke cycle (m) and is associated, among others, with anthropometric characteristics of the swimmer and/or their technical ability, and depends on the propulsive force produced by the propulsive segments (Barbosa *et al.*, 2010).

SI and η_p are estimators for overall swimming efficiency (Costill *et al.*, 1985). *SI* assumes that, at a given v , the swimmer with greater *SL* has the most efficient swimming technique (Costill *et al.*, 1985). η_p is defined as the work that is effectively used to propel the swimmer forward and depends on anthropometric characteristics of the swimmer and his/her technical skills (Toussaint, 1990). Contrarily to other sport activities where minimal differences in efficiency are observed among subjects with different technical abilities, the efficiency of swimming is deeply influenced by training and skill. Thus, it becomes important to understand the possible changes in the technical parameters of swimming during aging. It was reported that *SI* and η_p increase with training in elite swimmers (Costa *et al.*, 2012b). However, the analysis of how the kinematics parameters change throughout a season has yet to be performed for masters athletes.

Among the energetic factors are the maximal blood lactate concentration after exercise (Termin and Pendergast, 2000) (La_{peak}), velocity at 4 mmol·l⁻¹ of blood lactate concentration (v_4) and maximal oxygen uptake (VO_{2max}). Following and during exercise in elderly individuals, in general, both lactate production and removal are reduced with respect to younger counterparts. Ageing causes changes in body composition that alter the muscle structure and reduce the ability to perform exercises requiring strength and power. v_4 is described as an aerobic capacity indicator. VO_{2max} represents the maximal capacity both to transport and utilize the oxygen. Among physiological determinants of endurance exercise performance, a progressive reduction in VO_{2max} appears to be the primary mechanism associated with declines in endurance performance with age, followed by a reduction in lactate threshold (i.e. the exercise intensity at which blood lactate concentration increases significantly above baseline) (Tanaka and Seals, 2008). VO_{2max} declines approximately 10% per decade after age 25-30 years in healthy sedentary adults of both genders (Eskurza *et al.*, 2002). Beyond these, muscle strength and power also inexorably decline with ageing (Macaluso and Vito, 2004).

Scientific literature in masters swimmers simply reports cross-sectional data about their physiological and biomechanical characteristics (Zamparo *et al.*, 2012a). Longitudinal data are reduced when compared to their young and elite counterparts, focusing exclusively on performance (Donato *et al.*, 2003) and energy cost (Zamparo *et al.*, 2012b) adaptations based on race time's progression. To the best of our knowledge, it seems there is a lack of scientific evidence regarding masters swimmers energetic and biomechanical adaptations throughout a training season.

The aim of this research was to assess the performance, physiological and biomechanical parameters in masters swimmers in three distinct TPs over one season. It was hypothesized an improvement on performance, energetic and biomechanical variables throughout the season.

Methods

Subjects

Twenty three masters swimmers volunteered to serve as subjects (34.9±7.4 years old; 2014 FINA Points: 286.0±121.7): twelve male (age of 35.0±7.5-y; 1.75±0.06-m of height; 74.8±7.7-kg of body mass; 170.42±27.77 s of personal record in 200 m freestyle event; 2014 FINA points 315.0±128.6) and eleven female (age of 34.7±7.3-y; 1.63±0.05-m of height; 58.5±5.4-kg of body mass; 200.72±25.02 s of personal record in 200 m freestyle event; 2014 FINA points 254.3±110.8). The conversion of times into FINA points was made using the procedure suggested by Daly and Vanlandewijck (1999).

Male and female swimmers, aged 30-50 years, were recruited by detailed announcements at a local swimming club. The following inclusion criteria were considered: (i) male or female; (ii) 25-50 years-old (iii) have a background as swimmer participating in national swimming events; (iv) be

engaged in a systematic masters swimming program. The exclusion criteria included: (i) any physical challenge; (ii) musculoskeletal injury, pathology or condition; (iii) pregnancy; (iv) more than 3 consecutive weeks of absence during the follow-up period.

All subjects gave their written informed consent before participation. The study was approved by the local ethics committee and is in accordance to the Declaration of Helsinki.

Study Design

A longitudinal research design was carried out, being swimmers evaluated on three different time periods over a season: December (TP₁), March (TP₂) and June (TP₃). Swimming training consisted in three sessions per week, involving low, medium and high aerobic tasks, sprint work and technical drills. Weekly training averaged 9.0 ± 1.7 km wk⁻¹. Throughout the season, the training of swimmers presented intensity corresponding to aerobic (TP₁: 92.81%; TP₂: 90.35%; TP₃: 91.36%) and anaerobic capacity (TP₁: 7.19%; TP₂: 9.65%; TP₃: 8.64%) (Figure 1). The training process was always accompanied by the research team with the coach of the team. The distinction between aerobic and anaerobic loads was carried out taking into account the considerations of Maglischo (2003) and using the same procedure of previous studies (Costa *et al.*, 2012b; Morais *et al.*, 2013).

In each TP, the 200 m freestyle performance, v_4 , La_{peak} , VO_{2max} , v_{200} , SF , SL , SI , η_p were collected.

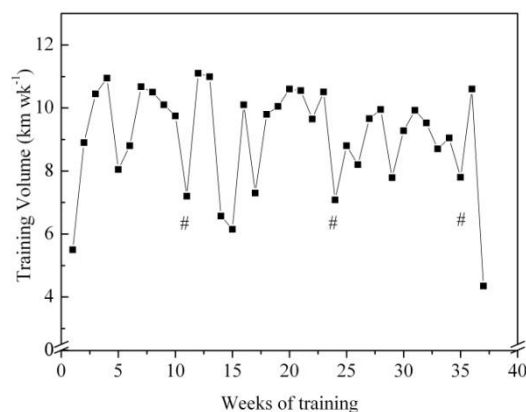


Figure 1. Total weekly volume of training throughout the three time periods. # indicates the test occasions.

Performance Data Collection

Swimming performance was assessed based on time lists of the 200 m freestyle event during local, regional and national competitions. The time between the official competition and the testing day never exceeded two weeks.

Energetic and Biomechanical Data Collection

An incremental 5 × 200 m step test, in a 25 m pool, was used to evaluate the swimmers' energetic adaptations (Thanopoulos, 2010). Push-off starts were used in each bout. The starting velocity was set at approximately 0.3 m·s⁻¹ less than the swimmer's best performance, representing a low training pace (Laffite *et al.*, 2004), and the increment between bout was 0.05 m·s⁻¹, ensuring that the final bout was performed at maximal velocity. The rest period is long enough to allow for repose so that the swim intensity incrementally increases from the first to the last repetition of the swimming task. Underwater pacemaker lights (GBK-Pacer, GBK Electronics, Aveiro, Portugal), located on the bottom of the pool, were used to control the swimming speed and to help swimmers to keep an even pace along each lap. In addition, elapsed time for each trial was measured with a stopwatch (SEIKO S141) by an exporter evaluator, as backup.

Oxygen uptake (VO_2) was measured immediately after each trial (Kb4², Cosmed, Rome, Italy). Swimmers were instructed to breath during the last cycle before touching the wall. After finishing the trial, the swimmer leaned on the wall, while an operator fixed a portable mask on his face during all recovery period. No breathing cycle was made until the portable mask was on the swimmer's face. The VO_2 value (in ml·kg⁻¹·min⁻¹), reached during each step of the protocol, was estimated using the backward extrapolation of the oxygen (O_2) recovery curve. VO_{2max} was considered to be the mean value in the 6 s after the VO_2 detection during the recovery period (Laffite *et al.*, 2004). The first measurement of VO_2 values, before the highest VO_2 measurement, was not considered, because it corresponded to the device adaptation to the sudden change of respiratory cycles and to O_2 uptake. The device adaptation never exceeded 2 s (Costa *et al.*, 2012b; Laffite *et al.*, 2004).

Fingertip capillary blood samples were collected before the 200 m and, also, at the end, and in the 3rd, 5th, and 7th minutes after finishing the protocol. Samples were then analyzed for blood lactate concentrations (Accusport, Boehringer Mannheim, Germany). La_{peak} was considered to be the highest blood lactate concentration in post exercise condition (Termin and Pendergast, 2000). 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.

Swimming velocity (v) is the ratio of the distance to the elapsed time to travel that distance, and it was measured considering the mean value obtained in each lap (measured between 5 m and 20 m):

$$v = \frac{d}{t} \tag{1}$$

where v is the swimming velocity (in m·s⁻¹), d is the distance (in m) and t (in s) is the time required to travel that distance.

The biomechanical profile was determined based on the measurement of SF (in Hz), SL (in m), SI (in $m^2 \cdot c^{-1} \cdot s^{-1}$) and η_p (in %). 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).

SL was estimated as being (Craig *et al.*, 1985):

$$SL = \frac{v}{SF} \quad (2)$$

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

$$SI = v \cdot SL \quad (3)$$

where SI is the stroke index (in $m^2 \cdot c^{-1} \cdot s^{-1}$), v is the swimming velocity (in $m \cdot s^{-1}$) and SL is the stroke length (in m).

η_p was also estimated as being (Zamparo *et al.*, 2005):

$$\eta_p = \left(\frac{v \cdot 0.9}{2\pi \cdot SF \cdot l} \right) \cdot \frac{2}{\pi} \quad (4)$$

where v is the swimming velocity (in $m \cdot s^{-1}$), multiplied by 0.9 to take into account that, in front crawl, about 10% of forward propulsion is produced by the legs, SF is the stroke frequency (in Hz) and l is the arm's length (in m). 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 4 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 at v_{200} performance.

Statistical Procedures

The normality of all distributions was verified using Shapiro-Wilks tests. Parametric or non-parametric tests were selected accordingly. Mean plus one standard deviation and quartiles were computed for each time period. The relative frequency of variation (i.e. percentage of change) between time periods was also reported.

Data variation was assessed with ANOVA repeated measures, followed by the Bonferroni post-hoc test, as well as the Wilcoxon Signed-Rank Test, to assess differences between time periods (TP₁-TP₂; TP₁-TP₃; TP₂-TP₃). The level of statistical significance was always set at $P \leq 0.05$.

Results

Improvements were observed for masters performance throughout the season, with a decrease from TP₁ to TP₃ (TP₁-TP₂: -1.9%, $p=0.03$; TP₂-TP₃: -2.2%, $p=0.01$ and TP₁-TP₃: -4.1%, $p<0.001$) (Figure 2a). v_{200} increased from TP₁-TP₂ (2.9%, $p=0.03$), TP₂-TP₃ (1.9%, $p=0.04$) and TP₁-TP₃ (4.8%, $p=0.01$) (Figure 2b and Table 1).

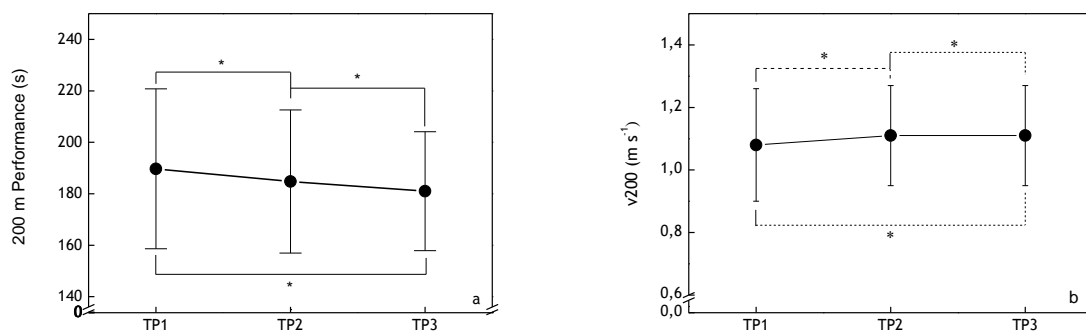


Figure 2. Mean \pm SD values of the 200 m freestyle performance (a) and v_{200} (b) in the three TPs. (*) significant differences in 200 m performance between TP₁-TP₂ ($p=0.03$), TP₂-TP₃ ($p=0.01$) and TP₁-TP₃ ($p<0.001$); in v_{200} between TP₁-TP₂ ($p=0.03$), TP₂-TP₃ ($p=0.04$) and TP₁-TP₃ ($p=0.01$).

Table 2 shows the correlation between v_{200} changes and the biomechanical and energetic changes from TP₁-TP₂, TP₂-TP₃ and TP₁-TP₃. SF , SL , SI , η_p , La_{peak} , v_4 , and VO_{2max} presented no relationship with the v_{200} increment found between TP₁-TP₂ and TP₂-TP₃. Between TP₁-TP₃, a positive and significant correlation was found between changes in SF and v_{200} ($r=0.49$, $p=0.02$).

Analyzing the individual modifications, in TP₁-TP₂, the performance improvement in eleven of the twenty-three swimmers was concomitant with an increase in SL and a decrease in SF , two swimmers increased SF and decreased SL and five swimmers increased both parameters (SL and SF). The remaining five swimmers presented a decrease of v_{200} between TP₁-TP₂. In TP₂-TP₃, the performance improvement in six of the twenty-three swimmers was concomitant with an increase in SL and a decrease in SF , nine swimmers increased SF and decreased SL and one swimmer increased both parameters (SL and SF). The remaining seven swimmers presented a decrease of v_{200} . Between the first and the last TP, the performance improvement in seven of the twenty three swimmers was concomitant with an increase in SL and decrease in SF , seven swimmers increased SF and decreased SL and two swimmers increased both parameters (SL and SF). The remaining seven swimmers presented a decrease of v_{200} between TP₁-TP₃.

Table 1. 200 m Freestyle Performance (s) of male (M) and female (F) swimmers in the three TP

Swimmer	TP ₁	TP ₂	TP ₃
M1	158	153	152
M2	152	162	158
M3	224	229	211
M4	188	181	179
M5	232	242	220
M6	165	162	162
M7	169	167	167
M8	144	141	140
M9	159	162	162
M10	150	148	147
M11	188	186	183
M12	175	172	174
Mean±SD	175.33±28.26	175.42±30.91	171.21±24.24
F1	192	193	191
F2	183	180	185
F3	231	208	205
F4	210	205	200
F5	218	211	205
F6	207	207	195
F7	207	195	185
F8	220	211	197
F9	248	233	231
F10	171	163	168
F11	170	166	166
Mean±SD	205.18±24.47	197.45±20.97	193.45±18.12
M+F Mean±SD	189.61±30.06	185.96±28.36	181.87±23.91

Table 2. Correlation between the 200 m velocity (v_{200}) changes and the biomechanical and energetics variables changes from TP₁-TP₂, TP₂-TP₃, and TP₁-TP₃

	v_{200}		
	TP ₁ -TP ₂	TP ₂ -TP ₃	TP ₁ -TP ₃
<i>SF</i>	0.39	0.10	0.49*
<i>SL</i>	-0.01	-0.10	-0.02
<i>SI</i>	-0.02	-0.17	-0.17
η_p	0.02	-0.11	-0.02
$L a_{peak}$	-0.07	-0.12	0.14
v_4	-0.04	0.34	-0.09
VO_{2max}	0.29	0.24	-0.21

* Correlation is significant at the 0.05 level

Analyzing the individual modifications, in TP₁-TP₂, the performance improvement in eleven of the twenty-three swimmers was concomitant with an increase in *SL* and a decrease in *SF*, two swimmers increased *SF* and decreased *SL* and five swimmers increased both parameters (*SL* and *SF*). The remaining five swimmers presented a decrease of v_{200} between TP₁-TP₂. In TP₂-TP₃, the performance improvement in six of the twenty-three swimmers was concomitant with an increase in *SL* and a decrease in *SF*, nine swimmers increased *SF* and decreased *SL* and one swimmer increased both parameters (*SL* and *SF*). The remaining seven swimmers presented a decrease of v_{200} . Between the first and the last TP, the performance improvement in seven of the twenty three swimmers was concomitant with an increase in *SL* and decrease in *SF*, seven swimmers increased *SF* and decreased *SL* and two swimmers increased both parameters (*SL* and *SF*). The remaining seven swimmers presented a decrease of v_{200} between TP₁-TP₃.

Figure 3 presents the energetic adaptations throughout the season. $L_{a_{peak}}$ decreased from TP₁-TP₂ (-8.8%, $p=0.04$) and increased between TP₂-TP₃ (1.0%). From the first to the last TP, $L_{a_{peak}}$ decreased (-7.9%) (Figure 3a). v_4 increased from TP₁-TP₃ (3.5%, $p<0.001$), but remained unchanged from TP₁-TP₂ (1.8%) and TP₂-TP₃ (1.7%) (Figure 3b). VO_{2max} increased from the first to the last TP (TP₁-TP₂: 10.0%, $p<0.001$; TP₂-TP₃: 7.3%, $p=0.03$; TP₁-TP₃: 18.0%, $p<0.001$) (Figure 3c).

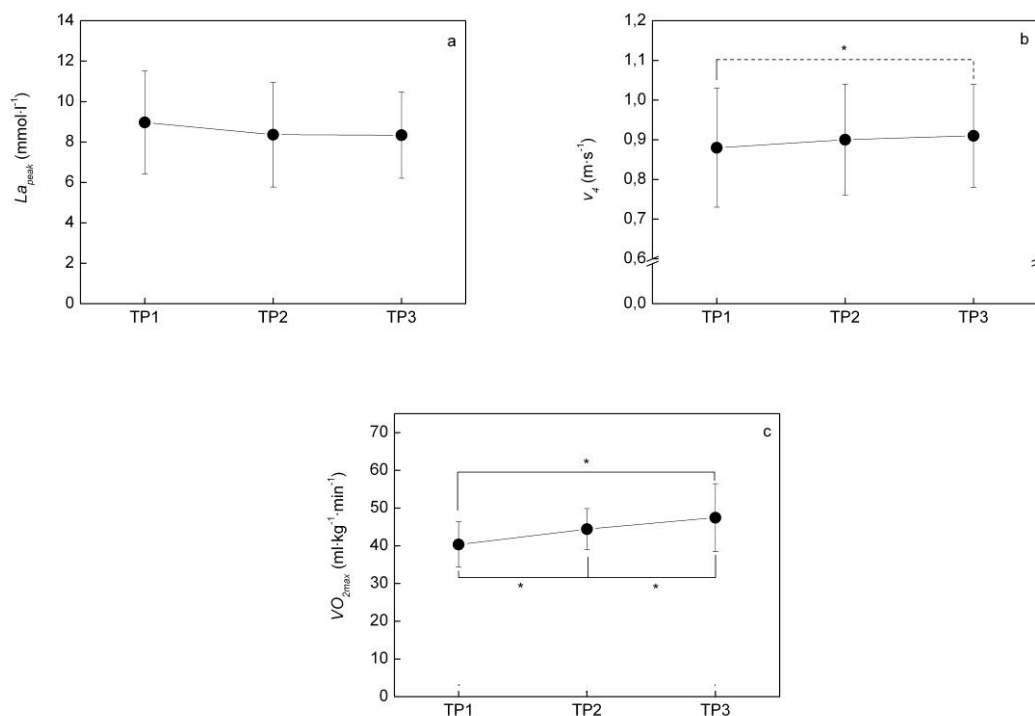


Figure 3. Mean±SD values of $L_{a_{peak}}$ (a), v_4 (b) and VO_{2max} (c) in the three TPs. (*) significant differences in $L_{a_{peak}}$ between TP₁-TP₂ ($p=0.04$); v_4 between TP₁-TP₃ ($p<0.001$); VO_{2max} between TP₁-TP₂ ($p<0.001$), TP₂-TP₃ ($p=0.03$) and TP₁-TP₃ ($p<0.001$).

Figure 4 presents the variation in biomechanical variables (SF and SL). Data reported a decrease in SF from TP_1 - TP_2 (-5.1%, $p<0.001$), remained unchanged between TP_2 - TP_3 (0.1%) and decreased from TP_1 - TP_3 (-5.1%, $p=0.04$) (Figure 4a). In contrast, SL exhibited an increase between TP_1 - TP_2 (5.7%, $p=0.02$) and TP_1 - TP_3 (5.1%, $p=0.04$). From TP_2 - TP_3 , SL presents a non-significant decrease (-0.5%) (Figure 4b).

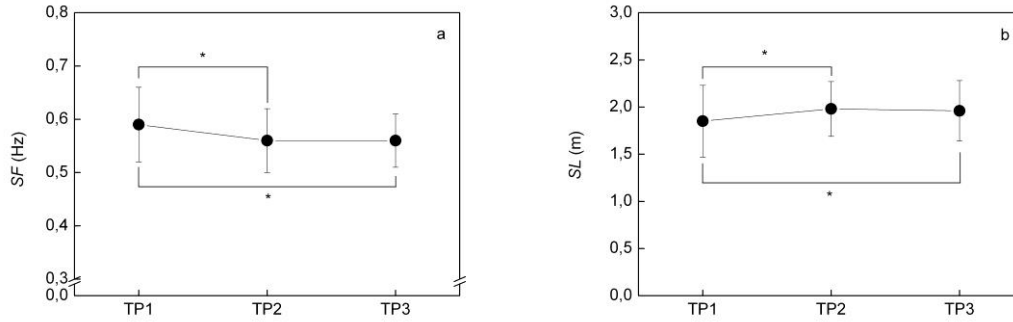


Figure 4. Mean \pm SD values of SF (a) and SL (b) in the three TPs. (*) significant differences in SF between TP_1 - TP_2 ($p<0.001$), TP_1 - TP_3 ($p=0.04$); SL between TP_1 - TP_2 ($p=0.02$), TP_1 - TP_3 ($p=0.04$).

SI and η_p are represented in Figure 5. Concerning SI (Figure 5a) significant increases were observed among TP_1 - TP_2 (5.4%, $p<0.001$) and TP_1 - TP_3 (6.8%, $p=0.04$). For TP_2 - TP_3 , there is no significant increase in SI (1.4%). Finally, η_p (Figure 5b) presents significant increases between TP_1 - TP_2 (6.4%, $p<0.001$) and TP_1 - TP_3 (6.3%, $p<0.001$). For TP_2 - TP_3 , there is no significant decrease in η_p (-0.1%). In all the biomechanical variables, no differences were found between TP_2 - TP_3 .

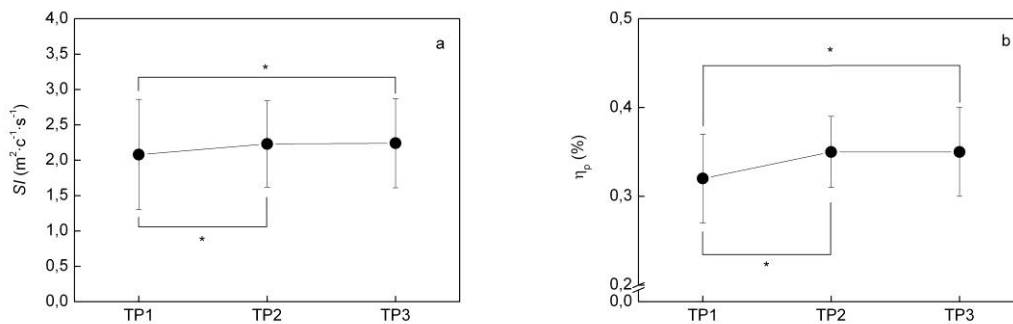


Figure 5. Mean \pm SD values of SI (a) and η_p (b) in the three TPs. (*) significant differences in SI between TP_1 - TP_2 ($p<0.001$), TP_1 - TP_3 : ($p=0.04$) and η_p between TP_1 - TP_2 ($p<0.001$) and TP_1 - TP_3 ($p<0.001$).

The energetic variable with higher percentage of changes throughout the season was VO_{2max} (18.0% between TP₁-TP₃), while SI was the biomechanics variable with larger percentage of changes (6.8% between TP₁-TP₃).

Discussion

The purpose of this study was to analyze the changes in performance, energetic and biomechanical profiles of masters swimmers throughout a season. The main results were the significant changes observed in performance, energetic (except La_{peak}) and biomechanical profiles throughout the season in masters swimmers.

Performance

The 200 m performance improved significantly from TP₁-TP₂ mainly due to the improvement of SL and η_p . Considering these results, it seems that, between TP₁-TP₂, there was an improvement in the swimming technique, corroborated by the significant increase of η_p . It is recognized that SL is a good propulsive efficiency indicator and it can be used to evaluate progress in the technique level. It was expected that, in swimmers with a lower performance level, SL and the effectiveness of propulsive force represented important factors affecting performance (Gatta *et al.*, 2006), especially in the first months of the training season, where the aerobic loads performed in the training allowed swimming at low velocities, focusing on technical aspects of the stroke mechanics and, thus, improving their technical ability. However, to improve performance, swimmers can also act on SF (Huot-Marchand *et al.*, 2005). In the present study, we can also observe that although SF did not change significantly over the season, a slightly increment in SF was found between TP₂-TP₃, which may be responsible for the improvement of performance between these two TPs. We also found that, between TP₂-TP₃, more swimmers improved their v_{200} due to an increase in SF than SL . Considering these results, it seems that each swimmer uses the most freely chosen combination to reach higher performances throughout the season. This result, associated with the positive relationship found between the increase in v and the increase in SF , with a significant value found in TP₁-TP₃ (Table 2), reveals the importance of SF on performance. Thus, a better performance appears to be dependent on a higher SF . These results highlight the role of both SL and SF for overall performance, even in masters swimmers. The absence of significant correlation between changes in v_{200} and energetic variables could mean that, in this age-group, the performance seems to be more dependent on technical than energetic factors.

The increase of the value of VO_{2max} results in a lower lactate production which becomes important considering that when the production of lactate exceeds its removal, it leads to the inhibition of contraction of muscle fibers (due to decreased pH), decreasing v .

Energetics

A decrease in La_{peak} was found between TP₁-TP₂ and TP₁-TP₃ (-8.8% and -7.9%, respectively). The assessment of La_{peak} is related with anaerobic capacity and the absence of significant improvements in this variable is probably due to the lower percentage dedicated to anaerobic workout and, also, to the decrease found in anaerobic capacity with ageing (Reaburn and Dascombe, 2009).

Comparing the values obtained in this study with the work of Benneli *et al.* (2007) (10.8 ± 2.8 mmol·l⁻¹ in women, and 14.2 ± 2.5 mmol·l⁻¹ in men), the values obtained here are lower (TP₁: 8.97 ± 2.55 mmol·l⁻¹; TP₂: 8.36 ± 2.59 mmol·l⁻¹; TP₃: 8.34 ± 2.13 mmol·l⁻¹). This may be attributed to the context in which the test was held, since in the study of Benneli *et al.* (2007) data were collected at the end of the World Masters Championships which provides greater motivation for carrying out the maximum effort.

v_4 is important for determining the aerobic capacity of the swimmers and it was demonstrated in elite swimmers that this capacity can be improved with training (Costa *et al.*, 2012; Pyne *et al.*, 2001). In the present study, v_4 increases throughout the three TPs. Generally, in young and elite swimmers, most gains in v_4 occur in the early months of the beginning of the season, due to an increase in training volume (Ryan *et al.*, 1990; Sharp *et al.*, 1984). This is as result of training induced adaptations which increase the muscle's ability to produce energy aerobically (Ryan *et al.*, 1990) thus reducing the rate of muscle glycogen use and lactate formation (Ryan *et al.*, 1990). Thereafter, aerobic capacity remains almost stable until the end of the season. In masters swimmers, we have also found a significant increase in v_4 with the increment in training volume verified from TP₁-TP₂ (109370 m and 113400 m, respectively). In the remainder of the season (TP₂-TP₃), v_4 presented a non-significant increase (1.6%) which may be due to the higher prevalence of aerobic workout during their training throughout the season (and not only at the beginning of the season), at the expense of strength, speed, and power that occurs in young and elite swimmers (Weir *et al.*, 2002).

The significant increase and the fact that VO_{2max} was the variable with higher percentage of changes throughout the season corroborate the idea mentioned in the previous paragraph. Studies performed with elite swimmers showed that VO_{2max} remained virtually unchanged throughout a season (Reaburn and Dascombe, 2009). However, masters swimmers have a lower sportive level, with a greater margin for improvement.

Biomechanics

For biomechanical variables, significant changes were observed throughout the season, especially for TP₁-TP₂ and TP₁-TP₃ and no differences were found in any of the biomechanical variables between TP₂-TP₃. This fact may be ascribed to the concept of detraining. In the transition between two seasons (off-season), if the athletes do not practice they probably lose the effects of its high performance. In this case, the tests in TP₁ were performed when the subjects had few training

sessions. Moreover, the individual response to a training regimen seems to depend to a great extent on one's initial performance level and the possibility for a performance improvement is higher as the initial level is lower. The performance level of the subjects is not high as evidenced by their personal record in 200 m freestyle event (185.20 ± 31.51 s).

The significant decrease in SF between TP_1 - TP_2 and TP_1 - TP_3 may mean that, with training, swimmers have learned to perform a more effective stroke and do not need to do so many strokes.

SL exhibits a significant increase between TP_1 - TP_2 and TP_1 - TP_3 . The increase of SL is generally related to a more forceful and effective stroke (Zamparo, 2006), revealing an improvement in the swimming technique. Swimmers comprising the sample are very heterogeneous in relation to their swimming experience: we have ex-swimmers with participations in national championships when they were young and individuals who started swimming a few years ago. These "recent swimmers" will have necessarily less technical skill than ex-swimmers so, with training, these subjects may be more able to present a larger improvement on the swimming technique.

The significant enhancement found in SI may be explained by the increase in v and SL , as SI is given by the product of v and SL .

Finally, the significant increase found in η_p may be due to the relationship between η_p and SF : lower values of SF , for a given velocity, lead to higher values in η_p (Zamparo, 2006).

Table 3 presents the biomechanics variables (v , SF , SL , SI and η_p) obtained in other studies.

Table 3. Biomechanics variables (v , SF , SL , SI and η_p) obtained in other studies

Authors	v ($m \cdot s^{-1}$)	SF (Hz)	SL (m)	SI ($m^2 \cdot c^{-1} \cdot s^{-1}$)	η_p
Favaro and Lima. (2005)	1.47 ± 0.27	0.65 ± 0.17	1.57 ± 0.14	2.32 ± 0.57	---
Zamparo <i>et al.</i> (2006)	1.29 ± 0.19	0.65 ± 0.17	2.04 ± 0.27	---	0.36 ± 0.08
Zamparo <i>et al.</i> (2012a)	0.93 ± 0.10	0.41 ± 0.06	2.27 ± 0.25	---	0.34 ± 0.05
Gatta <i>et al.</i> (2006)	1.39 ± 0.09	0.67 ± 0.06	2.10 ± 0.20	---	---
TP1	1.08 ± 0.18	0.59 ± 0.07	1.85 ± 0.38	2.08 ± 0.78	0.32 ± 0.05
TP2	1.11 ± 0.16	0.56 ± 0.06	1.98 ± 0.29	2.23 ± 0.61	0.35 ± 0.04
TP3	1.11 ± 0.16	0.56 ± 0.05	1.96 ± 0.32	2.24 ± 0.63	0.35 ± 0.05

Favaro and Lima (2005) obtained higher values of v , SF and SI compared to ours. The type and intensity of effort may explain these differences. Thus, the race accomplished in Favaro's study was a 50 m distance, at maximal intensity, so, since it is a shorter distance, a higher v is expected. In the study of Zamparo (2006), the subjects swam 50 meters (in a 50 m long swimming pool) at constant v and SF , and repeated the swim at three to four different velocities, self-selected by them. Once the distance is shorter in the study of Zamparo (2006) (50 m vs. 200 m), as expected, the v achieved is higher ($1.29 \text{ m}\cdot\text{s}^{-1}$ vs. $1.11 \text{ m}\cdot\text{s}^{-1}$, respectively). For the study of Zamparo *et al.* (2012a) the explanation for the lower v is the test accomplished: 240 s at a submaximal velocity vs. 200 m at a maximal velocity result in different performances (240 s vs. TP_1 200 m= 189.68 ± 31.07 s; TP_2 200 m= 184.72 ± 27.80 s; TP_3 200 m= 181.00 ± 23.13 s, respectively) and, consequently, in a lower v .

The reason for the higher SF found by Favaro and Lima (2005), compared to our study, is that in shorter distances (50 m), v increases at the expense of the increase of SF and not of SL . Comparing with Zamparo's results (Zamparo, 2006), the difference found in SF may be due to the different methodology used to calculate SF . Zamparo (2006) used the average time taken to complete five strokes to calculate SF , while in this study we used the average time taken to complete three strokes. In relation to the results of Zamparo *et al.* (2012a), they have obtained lower SF values due to the different intensity used to perform the test. Thus, at submaximal velocity, v is achieved by a smaller SF and a larger SL (Zamparo *et al.*, 2012a).

Favaro and Lima (2005) presented a lower SL than the present study which may be explained by the trend revealed by SL , increasing with distance increase, rather than SF (Zamparo *et al.*, 2012a). Contrariwise, Zamparo (2006) obtained higher values of SL in a 50 m race, at submaximal speed. In this case, the performance level of the subjects may be the reason for this result. Zamparo used subjects with good technical skill.

The fact that η_p was higher in the study of Zamparo (2006) may be due to the higher level performance of the swimmers in the sample, which is considered medium to good. On the other hand, the anthropometric characteristics of the swimmers, namely the arm length, may have influenced the value of η_p , once the shorter shoulder-to-hand distance (l) leads to higher values in η_p (0.60 ± 0.03 m and 0.57 ± 0.01 m vs. 0.73 ± 0.06 m). Thus, it would be expected that the value obtained by Zamparo (2006) is higher than the present study.

Also, in the other study performed by Zamparo *et al.* (2012a), the result of SL is greater than those obtained in our study. Being aware that SL is larger at a low swimming velocity and tends to decrease at maximal speeds (Zamparo, 2006), an explanation for this fact could be the type of test carried out in each study. Thus, while in Zamparo *et al.* (2012a) study males swam 4 minutes at submaximal velocity, in the present study variables were assessed over 200 m at a maximal intensity ($v=0.93\pm 0.10 \text{ m}\cdot\text{s}^{-1}$ vs. $v=1.11\pm 0.16 \text{ m}\cdot\text{s}^{-1}$, respectively).

The data of v , SL and SF reported by Gatta *et al.* (2006) were higher than those obtained in the present study probably due to the test performed. In the study of Gatta *et al.* (2006), data collection was made in real conditions of a swimming event, namely at a FINA World Masters Championship, contrary to what was observed in our study (simulated 200 m event). Furthermore, the level performance of the subjects was quite different: the participants in Gatta *et al.* study (2006) were highly trained athletes.

Conclusions

Masters swimmers improved significantly their 200 m freestyle performance over a season. In the first months of the training season there was an improvement in the swimming technique (SL). From mid phases until the end of the season, SF also acted on performance. Each swimmer used an individual strategy, combining SF and SL , to reach higher performances throughout the season. Although we found improvement in energetic factors throughout the season, in this age-group, performance seems to be more dependent on technical than energetic factors.

Study 3

Changes of the energetic profile in masters swimmers over a season

Abstract

Aim: The aim of this study was to track and compare the changes of performance and energetic profile of male and female masters swimmers during a season.

Methods: Eleven female (age: 34.7 ± 7.3 -y) and fourteen male (age: 35.6 ± 7.4 -y) with 4.2 ± 3.7 -y and 3.9 ± 1.6 -y of experience in masters, respectively, performed an all-out 200 m freestyle to evaluate total energy expenditure (E_{tot}), aerobic (Aer), anaerobic lactic (AnL) and alactic ($AnAl$) contributions. The oxygen uptake (VO_2) was measured immediately after the 200 m trial and the VO_2 reached during the trial was estimated through the backward extrapolation of the oxygen recovery curve. Fingertip capillary blood samples were collected before the 200 m trial and 3, 5, and 7 minutes after its end.

Results: Significant differences were observed between male (TP_1 : 177.50 ± 30.96 s; TP_2 : 174.79 ± 29.08 s; TP_3 : 171.21 ± 22.38 s) and female (TP_1 : 205.18 ± 24.47 s; TP_2 : 197.45 ± 20.97 s; TP_3 : 193.45 ± 18.12 s) for 200 m freestyle performance at the three time periods (TPs). Male presented higher E_{tot} in all TPs (TP_1 : 230.40 ± 48.40 kJ; TP_2 : 242.49 ± 37.91 kJ; TP_3 : 257.94 ± 46.32 kJ) compared with that found for female swimmers (TP_1 : 188.51 ± 35.13 kJ; TP_2 : 193.18 ± 20.98 kJ; TP_3 : 199.77 ± 25.94 kJ). Male presented higher AnL (TP_1 : 33.42 ± 6.82 kJ; TP_2 : 30.97 ± 8.73 kJ; TP_3 : 30.66 ± 8.27 kJ) and $AnAl$ (TP_1 : 30.61 ± 3.48 kJ; TP_2 : 30.61 ± 3.48 kJ; TP_3 : 30.60 ± 3.48 kJ) than female (TP_1 : 18.83 ± 8.45 kJ; TP_2 : 14.98 ± 4.17 kJ; TP_3 : 18.33 ± 8.66 kJ) and (TP_1 : 24.32 ± 2.22 kJ; TP_2 : 24.31 ± 2.23 kJ; TP_3 : 24.31 ± 2.23 kJ). Aerobic metabolism is the major contributor for E_{tot} both in male (TP_1 : 71.63 ± 4.99 %; TP_2 : 74.05 ± 5.03 %; TP_3 : 76.14 ± 4.46 %) and female swimmers (TP_1 : 76.87 ± 3.86 %; TP_2 : 79.40 ± 3.63 %; TP_3 : 78.40 ± 5.54 %).

Conclusions: The better performance obtained by male compared to female swimmers may be due to the different contributions of the energetic pathways. Aerobic metabolism was the major contributor to E_{tot} in a 200 m race, in both genders. Partial aerobic contribution was higher in female, while partial anaerobic contribution was greater in male.

Keywords: Training, gender, metabolic determinants, swimming season

Introduction

In recent years, given the growth in sport participation by masters athletes and the interest that individuals have in healthy sport participation with the advancing of age, the enhancement of the performance of masters athletes has received increasing attention (Ransdell *et al.*, 2009). Masters athletes include ancient elite athletes (Bongard *et al.*, 2007), “weekend athletes” who sporadically train and compete, and older competitors who have resumed training after long periods of physical inactivity (Maron *et al.*, 2001). The motivation beyond the participation of such athletes in competitions or of being involved in regular exercise is related with social aspects (*e.g.* enjoyment, travel, stress relief) and skill development factors like competition, physical fitness, health benefits, and personal challenge (Hastings *et al.*, 1995; Tantrum and Hodge, 1993). Swimming is probably the most or, at least, one of the most popular sports for masters athletes, providing an excellent opportunity to investigate the effects of age in the metabolic/biomechanical determinants of performance (Zamparo *et al.*, 2012b), avoiding physical inactivity as a potential confounding factor (Benelli *et al.*, 2007).

Swimming performance declines with age (Bongard *et al.*, 2007; Donato *et al.*, 2003; Tanaka and Seals, 1997) which may be a result of a decreased training external load¹⁰ and physiological response to exercise (Eskurza *et al.*, 2002). The ability to produce mechanical work in swimming is determined by the ability of the muscle cells to provide energy. There are three pathways to re-synthesize ATP (aerobic, anaerobic lactic and anaerobic alactic) and, therefore, to satisfy the energy requirements of muscles (Gastin, 2001). Therefore, the amount of energy necessary to perform one task (E_{tot}) represents the sum of aerobic and anaerobic (lactic and alactic) contributions (Gastin, 2001; Termin and Pendergast, 2000; Zamparo *et al.*, 2011).

The number of works dealing with performance-oriented masters swimmers is scarce and mainly focuses the effects of age on performance. There are no longitudinal or cross-sectional studies related with aerobic and anaerobic contributions in masters swimmers. For this reason, the data reported for elite swimmers will be used as reference.

On top of that, most swimming research is based on cross-sectional designs. There are some claims that only longitudinal designs (follow-up and intervention programs) can deliver deep insights about such relationships. The influence of training in performance (longitudinal designs) has already been addressed but only for younger, sub-elite and elite swimmers (Costa *et al.*, 2012b).

The aims of this research were: i) to assess the energetic contributions to the performance in masters swimmers over one season, and ii) to compare the performance and energetic profiles between genders. It was hypothesized that: i) swimming performance is influenced by energetic factors in both genders and, that ii) there is a gender difference in such relationship between male and female.

Material and Methods

A longitudinal research design was carried out, being the swimmers assessed in three different time periods (TPs) over a season: December (TP₁), March (TP₂) and June (TP₃). In each TP, the 200 m freestyle performance was assessed. Moreover, the oxygen uptake (VO_2) at the end of the 200 m and the maximal blood lactate concentration (from fingertip capillary blood samples), before the 200 m trial and, also, 3, 5, and 7 minutes after its end, were measured. Then, VO_2 was used to calculate the aerobic contribution (Aer) and the maximal blood lactate concentration (La_{peak}) was used to calculate the anaerobic lactic (AnL). The Aer , AnL and anaerobic alactic ($AnAl$) contributions enabled the estimation of the total energy expenditure (E_{tot}).

Subjects

Eleven female (age: 34.7 ± 7.3 -y; height: 1.63 ± 0.05 -m; body mass: 58.5 ± 5.4 -kg; body mass index: 22.1 ± 1.8 kg·m⁻²; 4.2 ± 3.7 -y of experience in masters age-group) and fourteen male (age: 35.6 ± 7.4 -y; height: 1.76 ± 0.06 m; body mass: 73.7 ± 8.3 kg; body mass index: 23.7 ± 2.7 kg·m⁻²; 3.9 ± 1.6 -y of experience in masters age-group) volunteered to serve as subjects. Twelve of the swimmers have been old athletes and the remaining ones started to swim only a few years ago.

All subjects gave their written informed consent before participation. The study was approved by the local ethics committee and is in accordance to the Declaration of Helsinki.

Procedures

Swimming performance was assessed based on time lists of the 200 m freestyle events during local, regional and national competitions. The time between the official competition and the testing day never exceeded more than two weeks.

A 200 m freestyle time trial performed in a 25 m length swimming pool was used to evaluate the performance and the swimmers' energetic adaptations. In addition, the elapsed time for 200 m was measured with a stopwatch (S141, Seiko, Tokyo, Japan) by two expert evaluators (ICC=0.98). The oxygen uptake (VO_2) was measured immediately after the end of the 200 m trial (K4b², Cosmed, Rome, Italy). The swimmers were instructed to breath during the last cycle before touching the wall. After finishing the trial, the swimmer leaned on the wall, while an operator fixed a portable mask on his/her face during all the recovery period. No breathing cycle was made until the portable mask was on the swimmer's face. The VO_2 (in ml·kg⁻¹·min⁻¹) reached during the trial was estimated through the backward extrapolation of the oxygen (O_2) recovery curve (mean value calculated within 6 s after the VO_2 detection, during the recovery period) (Laffite *et al.*, 2004). The first measure of VO_2 before the highest VO_2 measurement was not considered, because it corresponded to the device adaptation to the sudden change of respiratory cycles and to O_2 uptake. The device adaptation never exceeded 2 s (Costa *et al.*, 2010; Laffite *et al.*, 2004).

Fingertip capillary blood samples were collected before the 200 m and at the 3rd, 5th, and 7th minutes after finishing the trial. Samples were then used to determine blood lactate concentrations (Accusport, Boehringer Mannheim, Germany). The maximal blood lactate concentration (La_{peak}) was considered to be the highest blood lactate concentration in post-exercise condition (Termin and Pendergast, 2000).

The total energy expenditure (E_{tot} , in kJ) was calculated for the 200 m trial, corresponding to the swimmer's maximal effort (Zamparo *et al.*, 2011):

$$E_{tot} = Aer + Anl + AnAl \quad (1)$$

where Aer represents the aerobic contribution (in kJ) based on the total oxygen volume, Anl is the energy derived from lactic acid production (in kJ) and $AnAl$ stands for the energy derived from phosphocreatine (PCr) splitting in the contracting muscles (in kJ).

The total oxygen volume consumed during the 200 m was estimated as:

$$VO_2 = VO_{2net} \cdot t \cdot M \quad (2)$$

where VO_{2net} (in $ml \cdot kg^{-1} \cdot min^{-1}$) is the difference between the oxygen uptake measured during exercise and at rest, t (in min) is the total duration of the effort and M (in kg) is the mass of the subject. Aerobic contribution was then expressed in kJ assuming an energy equivalent (Zamparo *et al.*, 2011) of $20.9 \text{ kJ} \cdot lO_2^{-1}$.

The O_2 equivalent (in ml O_2) was obtained according to:

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

where La_{net} represents the difference between the lactate measured at the end of the 200 m trial and the lactate at rest; 2.7 is the energy equivalent (in ml $O_2 \cdot mmol^{-1} \cdot kg^{-1}$) for lactate accumulation in blood (di Prampero and Ferretti, 1999). Thus, the anaerobic contribution (in ml O_2) was expressed in kJ assuming (Zamparo *et al.*, 2011) an energy equivalent of $20.9 \text{ kJ} \cdot l O_2^{-1}$.

Lastly, the alactic contribution ($AnAl$) can be calculated as:

$$AnAl = PCr \cdot (1 - e^{-t/\tau}) \cdot M \quad (4)$$

where t is the time duration, τ is the time constant of PCr splitting at work onset (23.4 s, as proposed by Binzoni and colleagues (Binzoni *et al.*, 1992), and PCr is the phosphocreatine concentration at rest. The energy derived from the utilization of the PCr stores was estimated assuming that, in the transition from rest to exhaustion, the PCr concentration decreases by 18.5

$\text{mM}\cdot\text{kg}^{-1}$ muscle (wet weight) in a maximally active muscle mass (assumed to correspond to 30% of body mass) (Zamparo *et al.*, 2005) AnAl can be expressed in kJ by assuming (Capelli *et al.*, 1998) a P/O_2 ratio of 6.25 and an energy equivalent of 0.468 kJ·mM.

Statistical Procedures

The normality of distributions was verified using Shapiro-Wilks tests. Parametric or non-parametric tests were selected accordingly. Mean plus one standard deviation and quartiles were computed for each TP. Data variation was assessed with ANOVA repeated measures followed by the Bonferroni post-hoc test ($P\leq 0.05$), or Wilcoxon Signed-Rank Test ($P\leq 0.05$), to assess differences between time periods. The differences between genders were analyzed with Independent Sample T-Test, except aerobic contribution in TP₁, which was analyzed with the Mann-Whitney U Test ($P\leq 0.05$). Cohen's d was selected as effect size index with $0.20\leq d<0.50$ represents a small effect, $0.5\leq d<0.80$ represents a moderate effect, and $d\geq 0.8$ a large effect (Cohen, 1988).

Results

Swimming performance

The 200 m freestyle performance of males presented an insignificant improvement throughout the season (TP₁-TP₂: -1.5%; TP₂-TP₃: -2.0%; TP₁-TP₃: -3.5%). On the other hand, for females significant variations were found between TP₁-TP₂ (-3.8%), and TP₁-TP₃ (-5.7%). Comparing both genders, males always performed better than females (TP₁: $p=0.02$, $d=0.99$; TP₂: $p=0.04$, $d=0.89$; TP₃: $p=0.01$, $d=1.13$) (Figure1).

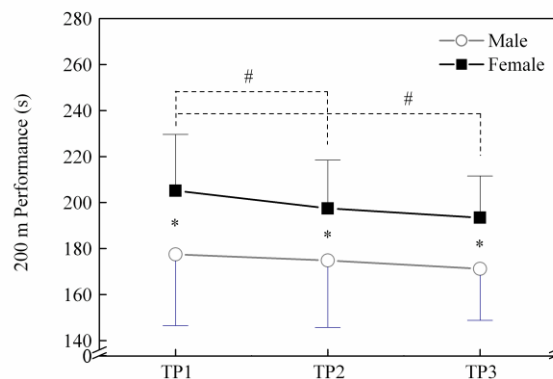


Figure 1. Mean \pm SD values of the 200 m freestyle performance in the three TPs. (*) significant differences between genders (TP₁: $p=0.02$; TP₂: $p=0.04$; TP₃: $p=0.01$). (#) significant differences in female 200 m performance between TP₁-TP₂ ($p<0.001$); TP₁-TP₃ ($p<0.001$).

Total energy expenditure

Dispêndio energético The E_{tot} value presented a negligible increase from TP₁-TP₂ (5.2%) and a significant one from TP₂-TP₃ (6.4%) and TP₁-TP₃ (12%) in males. The remaining increases were not significant in both genders. Females presented insignificant increases over the season (TP₁-TP₂: 2.5%; TP₂-TP₃: 3.4%; TP₁-TP₃: 6.0%). In all TPs, males presented a higher E_{tot} value than that calculated for females (TP₁: $p=0.02$, $d=0.99$; TP₂: $p<0.001$, $d=1.61$; TP₃: $p<0.001$, $d=1.54$) (Figure2).

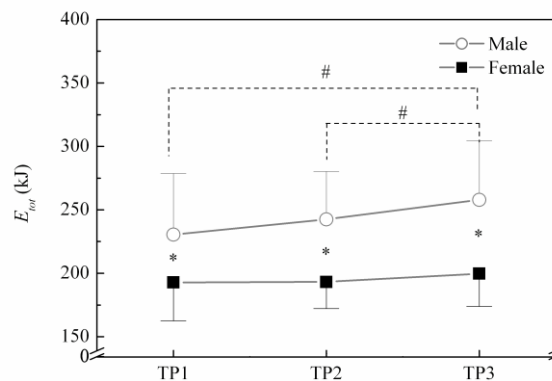


Figure 2. Mean \pm SD values of the energy expenditure (E_{tot}) in the three TPs. (*) significant differences between genders (TP₁: $p=0.02$; TP₂: $p<0.001$; TP₃: $p<0.001$). (#) significant differences in male E_{tot} between TP₂-TP₃ ($p=0.04$) and TP₁-TP₃ ($p<0.001$).

Energetic pathways

The aerobic contribution in male swimmers increased significantly from TP₁-TP₂, TP₂-TP₃ and TP₁-TP₃ (7.9%, 10.7% and 19.4%, respectively). However, female swimmers showed a smaller increase from TP₁-TP₂, TP₂-TP₃ and TP₁-TP₃ (5.9%, 2.1% and 8.1%, respectively). Comparing both groups, female swimmers presented a significantly lower aerobic contribution than males in TP₃ ($p=0.01$) (Figure 3). Cohen's d value presented a moderate effect in TP₁ ($d=0.58$) and a large one in TP₂ ($d=0.85$) and TP₃ ($d=1.20$).

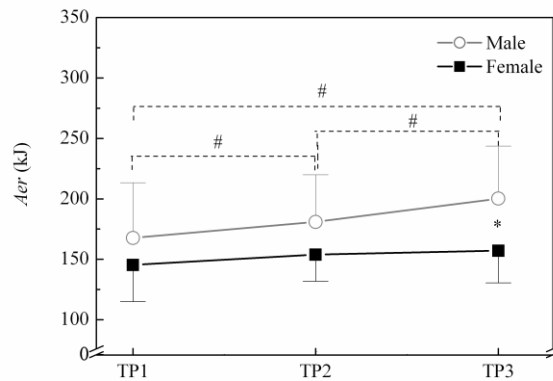


Figure 3. Mean \pm SD values of the aerobic contribution (*Aer*) in the three TPs. (*) significant difference between genders (TP₃ $p=0.01$). (#) significant differences in male *Aer* between TP₁-TP₂ ($p=0.03$); TP₂-TP₃ ($p=0.01$); TP₁-TP₃ ($p<0.001$).

The anaerobic lactic contribution (Figure 4) decreased for males, from TP₁-TP₂ (-7.3%), TP₂-TP₃ (-1.0%) and TP₁-TP₃ (-8.3%). In females, that contribution showed a decrease between TP₁-TP₂ (-20.4%), but increased from TP₂-TP₃ (22.4%) and finally decreased once again from TP₁-TP₃ (-2.7%). A higher anaerobic lactic contribution was found for males (TP₁: $p<0.001$, $d=1.90$; TP₂: $p<0.001$, $d=2.33$; TP₃: $p<0.001$, $d=1.46$).

A decrease in La_{peak} was determined for males throughout all TPs: TP₁-TP₂ (-3.9%); TP₂-TP₃ (-2.3%); TP₁-TP₃ (-6.1%) whereas La_{peak} in females decreased from TP₁-TP₂ (-11.6%), increased slightly from TP₂-TP₃ (3.1%) and decreased from TP₁-TP₃ (-8.1%). Comparing genders, the values of La_{peak} were higher in males (TP₁: 10.02 ± 2.08 mmol \cdot l⁻¹; TP₂: 9.63 ± 2.66 mmol \cdot l⁻¹; TP₃: 9.41 ± 1.88 mmol \cdot l⁻¹) compared to that measured for females (TP₁: 7.64 ± 2.54 ; TP₂: 6.75 ± 1.34 mmol \cdot l⁻¹; TP₃: 6.96 ± 1.60 mmol \cdot l⁻¹). Cohen's d revealed large effects in all TPs (TP₁: $d=1.03$; TP₂: $d=1.37$; TP₃: $d=1.40$).

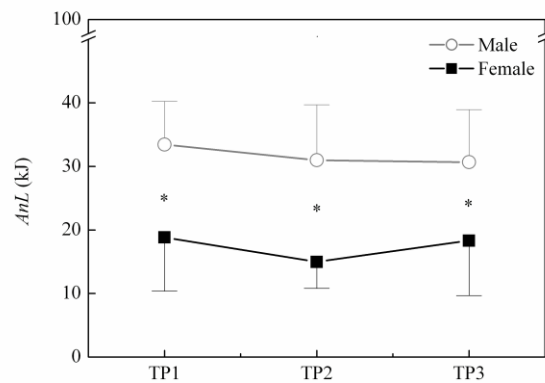


Figure 4. Mean \pm SD values of the anaerobic lactic contribution (AnL) in the three TPs. (*) significant differences between genders (TP₁: $p < 0.001$; TP₂: $p < 0.001$; TP₃: $p < 0.001$).

Finally, anaerobic alactic contribution (Figure 5) presented variations over time in the female group. Also, there were significant differences between genders (TP₁: $p < 0.001$, $d = 2.15$; TP₂: $p < 0.001$, $d = 2.15$; TP₃: $p < 0.001$, $d = 2.25$).

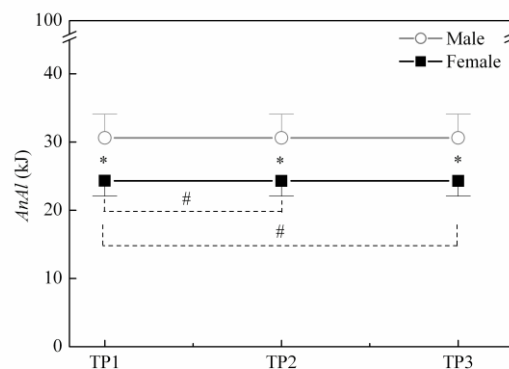


Figure 5. Mean \pm SD values of the anaerobic alactic contribution ($AnAl$) in the three TPs. (*) significant differences between genders (TP₁: $p < 0.001$; TP₂: $p < 0.001$; TP₃: $p < 0.001$). (#) significant differences in female $AnAl$ between TP₁-TP₂ ($p = 0.02$); TP₁-TP₃ ($p < 0.001$).

Partial contribution to total energy

Aerobic metabolism ($\%Aer$) was the major partial contributor for E_{tot} in both genders (table1). Anaerobic alactic ($\%AnAl$) and anaerobic lactic ($\%AnL$) metabolism were the second major contributors for E_{tot} in female and male, respectively. Male swimmers increased significantly $\%Aer$ from TP₁-TP₂ ($p = 0.03$, 3.4%) and TP₁-TP₃ ($p = 0.01$, 6.3%), whereas between TP₂-TP₃ a non-significant increase was obtained (2.8%). Female swimmers showed a non-significant increase from TP₁-TP₂ (3.3%), a decrease from TP₂-TP₃ (-1.3%) and, finally, an increase from TP₁-TP₃ (2.0%). Comparing both genders, female swimmers had a significantly higher $\%Aer$ in TP₁ ($p = 0.01$) and TP₂ ($p = 0.01$).

than male, whereas in TP₃ non-significant differences were found between genders. Cohen's *d* values revealed large effects in TP₁ ($d=1.17$) and TP₂ ($d=1.22$), but small in TP₃ ($d=0.45$).

In male swimmers, %AnL decreased significantly (-19%) between TP₁-TP₃ ($p=0.04$). However, from TP₁-TP₂ and TP₂-TP₃, %AnL showed non-significant decreases (-11.2% and -8.8%, respectively). In female swimmers, a non-significant decrease from TP₁-TP₂ (-20.0%), an increase from TP₂-TP₃ (17.1%) and a decrease from TP₁-TP₃ (-6.3%) were found. Comparing genders, male reached significantly higher %AnL in TP₁ ($p<0.001$) and TP₂ ($p<0.001$) than female. Considering Cohen's *d*, TP₁ and TP₂ had a large effect ($d=1.41$, $d=1.40$, respectively) while TP₃ presented a moderate one ($d=0.65$).

Male swimmers had a significant variation in %AnAl from TP₁-TP₂ ($p=0.04$), TP₂-TP₃ ($p=0.02$) and TP₁-TP₃ ($p<0.001$), decreasing -5.7%, -7.0% and -12.3%, respectively. On the other hand, female swimmers showed a non-significant decrease between TP₁-TP₂ (-4.1%), TP₂-TP₃ (-2.8%), TP₁-TP₃ (-6.7%). There were no significant differences in AnAl between genders and the Cohen's *d* values revealed small gender effects (TP₁: $d=0.18$; TP₂: $d=0.11$; TP₃: $d=0.22$) in all the three TP.

Table 1. Partial contribution of aerobic (%Aer), anaerobic lactic (%AnL) and anaerobic alactic (%AnAl) energy sources to total metabolic power output for both genders in the 200 m freestyle race over a full season

	Female			Male		
	TP ₁	TP ₂	TP ₃	TP ₁	TP ₂	TP ₃
%Aer	76.87±3.86*	79.40±3.63*	78.40±5.54	71.63±4.99*#	74.05±5.03*#	76.14±4.46#
%AnL	9.94±3.41*	7.95±2.76*	9.31±4.71	14.76±3.44*#	13.11±4.41*	11.96±3.32#
%AnAl	13.19±2.02	12.65±1.14	12.30±1.48	13.61±2.54#	12.84±2.13#	11.94±1.82#

(*) Significant differences between genders at the 0.05 level; (#) Significant differences in male between TP at the 0.05 level

Discussion

The aim of this study was to compare the changes of performance and energetic profile of male and female masters swimmers over a season. Female improved their performance throughout the season and presented lower Aer, AnL and AnAl contributions than male. The major contributor for E_{tot} in both genders was %Aer, followed by %AnL for male and %AnAl for female.

Swimming performance

Male and female masters swimmers improved their performance over the season, but only females presented a significant variation. The power and capacity of the immediate (ATP-PCr), short-term (anaerobic glycolysis), and long-term (oxidative phosphorylation) systems of energy production are the major factors in determining swimming performance (Toussaint and Hollander, 1994). Over the

season, we found a decrease in the anaerobic contributors in women, although only *AnAl* showed meaningful decreases. The *AnL* decreased by 20.4% from TP₁-TP₂ and, otherwise, *Aer* increased 5.9%. In male swimmers, in the same timeframe, the magnitude of *AnL* decrease was not so sharp as the one found in female (-7.3%). Moreover, the *Aer* improvement in males was similar to that seen in women (7.9%). Not surprisingly, men had better performances than women. This can be explained by the different contribution of the energetic pathways for the overall energy expenditure, which is notably the highest deliver from the anaerobic pathway (*AnL* and *AnAl*) by male compared to female.

Total energy expenditure

The increase in E_{tot} observed for both genders may be related with the increase in speed (Pendergast *et al.*, 2006). The improvement of swimming performance observed in the female swimmers may be one of the reasons for the slight increase verified in this cohort group. Comparing these results with those in the literature reported for younger and elite swimmers (Figueiredo *et al.*, 2011; Sousa *et al.*, 2013), both male and female masters presented lower E_{tot} values. This difference may rely on the sample characteristics (masters vs. elite) and age group (masters vs. young swimmers).

Energetic pathways

The higher aerobic workout in the masters training is one of the characteristics of this cohort. Comparing both genders, female swimmers present a significant aerobic contribution but lower than that found in their male counterparts. Two major reasons can be put forward (Weiss *et al.*, 2006): (i) lower blood hemoglobin concentration and; (ii) smaller size of the heart in relation to total muscle mass in females compared to men resulting in a less oxygen-carrying capacity.

The lack of improvement in *AnL* and *AnAl* for both genders can be attributed to the lower anaerobic training load (TP₁: 7.19%; TP₂: 9.65%; TP₃: 8.64%) throughout the season. Indeed, this is a characteristic reported for training sessions of masters athletes and periodization programs (Eskurza *et al.*, 2002). Furthermore, the decrease in anaerobic performance may also be attributed to changes in morphological factors (decreased muscle mass and type II muscle fiber atrophy), muscle contractile property (decreased rate of force development) and biomechanical aspects (changes in enzyme activity and decreased lactate production) arising from ageing (Reaburn and Dascombe, 2009). The *AnL* is also gender dependent. The *AnL* is also gender dependent. The major mechanism explaining this gender difference in anaerobic performance appears to be related to the greater rates of type II fiber atrophy (Macaluso and Vito, 2004) and to the lower peak blood lactate following anaerobic performance (Reaburn and Dascombe, 2009) exhibited by women. The type II fiber uses anaerobic metabolic processes to generate ATP, enabling short contraction time and the ability to produce high tension (Reaburn and Dascombe, 2009). Therefore, it is expected that

female swimmers muscles lose their ability for power strength as a result of the preferential fibers atrophy (Macaluso and Vito, 2004) and lower anaerobic contribution.

Women have less lean muscle in relation to total body weight and lower total stores of ATP, PCr and glycogen than men (McGlynn, 1996). Moreover, older women present type I and type II fibers with smaller areas than older men (Weir *et al.*, 2002).

Partial contribution to total energy

Aerobic metabolism was the major partial contributor for E_{tot} in both genders whereas anaerobic alactic and anaerobic lactic were the second one for females and males, respectively. Each system is best suited to provide a higher contribution to ATP re-synthesis according to the race characteristics. The role of aerobic energy system during high intensity exercise was reported by Gastein¹² and the data of the present study are in agreement with previous studies as well (Capelli *et al.*, 1998; Figueiredo *et al.*, 2011; Sousa *et al.*, 2013). The increase of %Aer verified in both genders is probably due to the higher percentage of workout focused on the aerobic capacity. The aerobic contribution expressed as a percentage of total work accomplishment is greater in female compared with male; otherwise %AnL and %AnAl are higher in male. Comparing both genders, the greater aerobic contribution, obtained in women compared to men may be assigned to the lower swimming speed achieved (Pendergast and Zamparo, 2011). For shorter distances, the anaerobic performance of elite male masters swimmers in 50 m and 100 m is 10% better than female masters. This can be explained by gender differences in muscle mass, lower La_{peak} and greater rates of type II fiber atrophy (Donato *et al.*, 2003).

Available literature reports that the major contributor to E_{tot} is also %Aer even though no study recruited masters swimmers as subjects. An effort of about 75 seconds derives energy from both aerobic and anaerobic energy sources and, from this moment, aerobic metabolism increases while the anaerobic contribution decreases (Gastein, 2011), which is what occurs in the 200 m trial. Masters swimmers have a higher prevalence of aerobic workout during their training whereas younger swimmers train for endurance, strength, speed, and power (Weir *et al.*, 2002). The %AnL values were lower than those obtained by Capelli *et al.* (1998), and Pendergast *et al.* (2006). With increasing age, anaerobic capacity decreases (Benelli *et al.*, 2007; Donato *et al.*, 2003; Reaburn and Dascombe, 2009) and the human skeletal muscle undergoes both structural and functional changes, the most striking of which are the reduction in muscle volume and muscle strength (Faulkner *et al.*, 2007). The area of muscle mass of old individuals was found to be significantly smaller and the total number of fibers significantly fewer than those of young individuals. The number of fibers seems to have the greatest influence on the muscle area. For all age groups, average type II fiber size is diminished with age while the size of type I fibers is much less affected, marking short contraction time and the ability to produce high tension, as already mentioned.

The %*AnAl* values are similar to those obtained by Capelli *et al.* (1998), and Sousa *et al.* (2013) being, however, lower than those of Pendergast *et al.* (2006) and Figueiredo *et al.* (2011). These differences may be attributed to the method of estimation of *AnAl*. Capelli *et al.* (1998) considered that PCr concentration decreases, in transition from rest to exhaustion, by $18.5 \text{ mM}\cdot\text{kg}^{-1}$ muscle (wet weight) in a maximally active muscle mass equal to 30% of the overall body mass (similar to our study), but Figueiredo *et al.* (2011) found that this value was $27.75 \text{ mM}\cdot\text{kg}^{-1}$ and assumed that the maximally active muscle mass corresponds to 50% of body mass. This last assumption does not seem to be appropriate for masters swimmers since, with age, there is a decrease in skeletal muscle mass (Doherty, 2001) whereby it is unlikely that 50% of the total mass corresponds to muscle mass. Thus, assuming the value of 30% of active muscle mass seems to be more appropriate for this age group.

Conclusions

The better performance obtained by male compared with female swimmers may be due to the different contributions of energetic pathways. Male swimmers present higher *Aer*, *AnL* and *AnAl* contributions than female. Aerobic metabolism was the major contributor to E_{tot} in a 200 m race, in both genders. Partial aerobic contribution was higher in female, while partial anaerobic contribution was greater in male.

Study 4

The effect of gender, energetics and biomechanics on swimming masters performance

Abstract

Purpose: Analyze the effect of gender and energetics on biomechanics and performance of masters swimmers over one season.

Methods: Twenty five masters swimmers were assessed three times during a season. An incremental 5×200 m step test was selected to evaluate velocity at 4 mmol·l⁻¹ of blood lactate concentration (v_4), maximal blood lactate concentration after exercise (La_{peak}), maximal oxygen uptake (VO_{2max}), stroke frequency (SF), stroke length (SL), stroke index (SI) and propelling efficiency of the arm stroke (η_p). The 200 m freestyle performance and average swimming velocity (v_{200}) were also monitored.

Results: Significant differences were observed between males and females for the 200 m freestyle performance, SL , SI and La_{peak} . Performance, biomechanics (SL , SI and η_p) and energetic variables (v_4 and VO_{2max}) have changed significantly throughout the season in female swimmers. In male, significant differences were found over the season in η_p and VO_{2max} . Gender presented a significant effect on SL , SI and La_{peak} . v_4 , SL , SI , and η_p had a large effect on performance.

Conclusions: Males masters swimmers have better performance, SL , SI and La_{peak} than female counterparts. Female masters swimmers enhanced significantly the 200m freestyle performance over a season due to the improvement in swimming technique (SL , SI and η_p) and energetic (v_4 and VO_{2max}). Non-significant improvements were observed for the males' performance. Gender has a significant effect on SL , SI and La_{peak} . Therefore, the performance is more dependent on technical factors than energetics.

Practical applications: In this age-group, the performance seems to be more dependent on technical than energy factors whereby, the training should aim to preserve the energetic factors as much as possible and, at the same time, develop the technical skills.

Keywords: Aging, season, technique, physiology, front crawl

Introduction

Physical exercise has a positive and meaningful effect on health (Bongard *et al.*, 2007). Nevertheless, aging affects the level of physical activity, and therefore physical fitness, due to a decrease in engagement in physical activity and a trend to train at lower exercise intensities (Weir *et al.*, 2002). Moreover, with advancing age, structural and functional impairment happens in most of the physiological systems, even in the absence of discernible disease. So, it is expected that human performances in sports also impair with aging (Bongard *et al.*, 2007; Donato *et al.*, 2003; Maharam *et al.*, 1999). Research with masters athletes provides a good chance to investigate age effects on the metabolic/biomechanic determinants of performance (Zamparo *et al.*, 2012b), excluding physical inactivity as a potential confounding factor (Benelli *et al.*, 2007).

The reasons beyond the participation of masters athletes in competitions and/or in regular exercise are the enjoyment, the health benefits (Tantrum and Hodge, 1993) and the best performance. For this reason, the identification of the factors and the magnitude of their influence in the swimming performance is an important aim. Swimming performance is determined by physiologic, biomechanic, and psychological factors whereby the development of these characteristics enhances the possibility of success (Anderson *et al.*, 2006). Therefore, the longitudinal assessment of the performance is important because it enables the analysis of the swimmer progression over a season induced by training (Costa *et al.*, 2010). Considering that masters swimmers have less practice sessions in comparison to younger counterparts and that their main focus is the build-up of endurance (Weir *et al.*, 2002), it is interesting to evaluate if a training program will have impact on energetics and biomechanics. Energetic variables, such as aerobic and anaerobic capacities, can be assessed at the concentration of 4 mmol·l⁻¹ of blood lactate levels (v_4), maximal oxygen consumption (VO_{2max}), and maximal blood lactate concentration after exercise (La_{peak}), respectively. These variables may be useful tools to monitor the effects of ageing on muscle metabolism. The biomechanical variables are useful parameters as indicators of swimming technique (Barbosa *et al.*, 2010) and include the stroke mechanics, such as stroke frequency (SF), stroke length (SL), stroke index (SI) and propelling efficiency of the arm stroke (η_p). In masters swimmers, the differences between genders may represent an interesting topic of research to find out if the effects of ageing are similar in male and female swimmers. However, the body of knowledge about this issue is scarce (Donato *et al.*, 2003) and few reports included cross-sectional data about their physiologic and biomechanic characteristics (Zamparo *et al.*, 2012a). Compared to young and elite counterparts, longitudinal research is reduced and exclusively focused on performance variations based on race time's progression (Donato *et al.*, 2003) and energy cost (Zamparo *et al.*, 2012b). As far as we can understand, it seems there is a lack of evidence about energetic and biomechanical adaptations of masters swimmers over time (e.g. a full season).

The aim of this research was to analyze the effect of energetic and gender on the performance and biomechanics of masters swimmers over one season. It was hypothesized that: i) gender influences the performance; ii) energetics influences the performance and biomechanics; iii) biomechanics influences the performance.

Methods

Subjects

Twenty-five subjects were recruited for this research. Eleven female swimmers (age: 34.7 ± 7.3 years old; height: 1.63 ± 0.05 m; body mass: 58.5 ± 5.4 kg) and fourteen male swimmers (age: 35.6 ± 7.4 years old; height: 1.76 ± 0.06 m; body mass: 73.7 ± 8.3 kg) volunteered to serve as subjects.

Male and female swimmers, aged 30-50 years, were recruited by detailed announcements at a local swimming club. The following inclusion criteria were considered: (i) male or female; (ii) 25-50 years-old (iii) have a background as swimmer participating in national swimming events; (iv) be engaged in a systematic master swimming program. The exclusion criteria included: (i) any physical challenge; (ii) musculoskeletal injury, pathology or condition; (iii) pregnancy; (iv) more than 3 consecutive weeks of absence during the follow-up period.

All subjects gave their written informed consent before participation. The study was approved by the local ethics committee and is in accordance to the Declaration of Helsinki.

Study Design

A longitudinal research design was carried out, with three evaluation moments over a season: December (TP₁), March (TP₂) and June (TP₃). Training programme consisted in three sessions per week, involving low, medium and high-aerobic sets, sprinting sets and drills. Training averaged 9.0 ± 1.7 km·wk⁻¹. Throughout the season, the training of swimmers presented an intensity corresponding to aerobic (TP₁: 92.81%; TP₂: 90.35%; TP₃: 91.36%) and anaerobic capacities (TP₁: 7.19%; TP₂: 9.65%; TP₃: 8.64%). In each TP, the 200 m freestyle performance, v_4 , $L_{a_{peak}}$, VO_{2max} , v_{200} , SF , SL , SI , η_p were collected.

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(Costa *et al.*, 2012; Morais *et al.*, 2013). In each TP, the 200 m freestyle performance, v_4 , La_{peak} , VO_{2max} , V_{200} , SF , SL , SI , and η_p were collected.

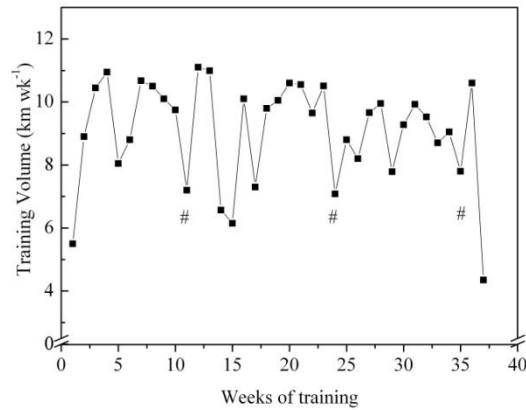


Figure 1. Total weekly volume of training throughout the three time periods. # indicates the test occasions.

Energetics and Biomechanics data collection

An incremental 5×200 m step test (25 m pool) was selected to evaluate the swimmers' energetic adaptations (Thanopoulos, 2010). The starting velocity was set at approximately $0.3 \text{ m}\cdot\text{s}^{-1}$ less than the swimmer's best performance, representing a low training pace (Laffite *et al.*, 2004). Underwater pacemaker lights (GBK-Pacer, GBK Electronics, Aveiro, Portugal) were placed on the bottom of the swimming pool to control the swimming pace along each lap. Time for each trial was clocked with a stopwatch (SEIKO S141) by an expert evaluator as backup.

Oxygen uptake (VO_2) was measured immediately after each trial (Kb4², Cosmed, Rome, Italy). The mean error in VO_2 in consecutive evaluations was $1.2\pm 0.23\%$. Swimmers were instructed not to breath during the last cycle before touching the wall. After finishing the trial, the swimmer leaned on the wall while an operator fixed a portable mask on his face during all recovery period. The VO_2 reached during each step of the protocol was estimated using the backward extrapolation of the oxygen (O_2) recovery curve. VO_{2max} was considered to be the mean value in the 6s after the VO_2 detection, during the recovery period (Laffite *et al.*, 2004). The first measurement of VO_2 before the highest VO_2 value was not considered, because it corresponded to the device adaptation to the sudden change of respiratory cycles and to oxygen uptake. The device adaptation never exceeded 2 s (Costa *et al.*, 2012b; Laffite *et al.*, 2004).

Fingertip capillary samples were collected before the 200 m, at the end, and in the 3rd, 5th, and 7th minutes after the protocol to assess lactate concentrations (Accusport, Boehringer Mannheim, Germany). La_{peak} was considered to be the highest blood lactate concentration in post exercise condition (Termin and Pendergast, 2000). v_4 was obtained by interpolation of the average lactate value ($4 \text{ mmol}\cdot\text{l}^{-1}$) on the exponential curve of lactate/speed relationship.

Swimming velocity (v) is the ratio between the distance and the time to travel that distance, and it was measured considering the mean value obtained in each lap with a stopwatch (measured between 5 m and 20 m). The same distance was used to measure SF (Hz), SL (m), SI ($m^2 \cdot c^{-1} \cdot s^{-1}$) and η_p (%). The ICC in all biomechanic variables ranged from 0.98 to 0.99. SF was recorded manually from three consecutive stroke cycles in each lap, with a chrono-frequency meter (Golfinho Sports MC 815, Aveiro, Portugal). Then, SF values were converted to International System Units (i.e. Hz).

SL was estimated as the ratio between swimming velocity and SF (Craig *et al.*, 1985). SI was computed as the product of the velocity of the swimmer during the 15 m recorded and the corresponding SL (Costill *et al.*, 1985). The propelling efficiency of the arm stroke (η_p) was estimated as being (Zamparo *et al.*, 2005):

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

where the factor 0.9 takes into account that, in front crawl, about 10% of forward propulsion is produced by the kicking, SF is the stroke frequency (Hz) and l is the arm's length (m), being 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 1 is, properly speaking, the Froude efficiency, considering that internal mechanical work is rather low and can be neglected in the range of swim velocity of these swimmers. All the energetic and biomechanical values were then estimated at v_{200} performance.

Performance Data Collection

Swimming performance was assessed based on time lists of the 200 m freestyle event during local, regional and national competitions. Time gap between the official event and the testing session took no longer than two weeks.

Statistical Procedures

Standard statistical methods were used for the calculation of the means and SDs. For the analysis of the statistical effect of energetic and biomechanic variables on performance in each TP, a univariate analysis of covariance (ANCOVA) was used, having as dependent variable the performance, as factor the gender, and SF , SL , SI , η_p , La_{peak} , v_4 and VO_{2max} as covariates. For the analysis of the statistical effect of energetic variables on biomechanic variable in each TP, a multivariate analysis of covariance (MANCOVA) was used, having as dependent variables SF , SL , SI , η_p , as factor the gender, and La_{peak} , v_4 and VO_{2max} as covariates. The normality of the residuals of MANCOVA was checked by applying the Kolmogorov-Smirnov test and the homogeneity of variance-covariance matrix was tested by the BoxMtest (TP₁: $M=30.198$, $F[10, 2183.5]=2.43$, $p \leq 0.05$; TP₂: $M=15.722$, $F[15, 1852.3]=1.26$, $p > 0.05$; TP₃: $M=33.830$, $F[10, 1852.3]=2.72$, $p \leq 0.05$). When the assumption was not verified ($p \leq 0.05$), it was selected the Pillai's Trace test statistics while when

the assumption was verified ($p > 0.05$) it was selected the Wilks' Lambda. When statistically significant differences were observed, an analysis of covariance (ANCOVA) was estimated for each dependent variable, followed by Bonferroni's post-hoc comparison tests. Partial eta squared (η_p^2) was selected as effect size index.

Results

Energetics. VO_{2max} , La_{peak} and v_4 were higher in males compared to females in all TPs (Figure 2). These differences were significant only for La_{peak} in all TPs (TP₁: $p=0.02$; TP₂: $p<0.001$; TP₃: $p<0.001$) with a significant and large effect of gender on this variable in TP₃ ($\eta_p^2=0.42$, $p<0.001$). VO_{2max} increased in male (8.5%, 11.1% and 20.5%) and female (12.2%, 1.2% and 13.5%) between TP₁-TP₂, TP₂-TP₃ and TP₁-TP₃, respectively (Figure 2a). A decrease in La_{peak} was determined for males throughout all TPs: TP₁-TP₂ (-3.9%); TP₂-TP₃ (-2.3%); TP₁-TP₃ (-6.1%) whereas La_{peak} in females decreased from TP₁-TP₂ (-11.6%), increased from TP₂-TP₃ (3.1%) and decreased from TP₁-TP₃ (-8.1%) (Figure 2b). An increase in v_4 was observed throughout the season in both genders: male's v_4 increased 1.1%, 2.2% and 3.3% between TP₁-TP₂, TP₂-TP₃ (in this case significantly) and TP₁-TP₃, respectively (Figure 2c). Female showed a non-significant increase between TP₁-TP₂ (2.28%), slight increase between TP₂-TP₃ (0.9%) and a significant increase between TP₁-TP₃ (3.14%).

A large effect of v_4 on biomechanic variables was found in all TPs (TP₁: $\eta_p^2=0.85$, $p<0.001$; TP₂: $\eta_p^2=0.88$, $p<0.001$; TP₃: $\eta_p^2=0.60$, $p<0.001$). In TP₁, we observed that v_4 has a large effect on SI ($\eta_p^2=0.56$, $p<0.001$), followed by η_p ($\eta_p^2=0.47$, $p<0.001$) and SL ($\eta_p^2=0.38$, $p<0.001$). In TP₂, data showed a large effect of v_4 on SI ($\eta_p^2=0.58$, $p<0.001$) and η_p ($\eta_p^2=0.32$, $p=0.01$), and a moderate-sized effect on SL ($\eta_p^2=0.24$, $p=0.02$). In the last TP, v_4 has a large effect on SL ($\eta_p^2=0.52$, $p<0.001$), followed by SI ($\eta_p^2=0.50$, $p<0.001$) and η_p ($\eta_p^2=0.50$, $p<0.001$). La_{peak} and VO_{2max} did not have a significant effect on biomechanic variables in all TPs.

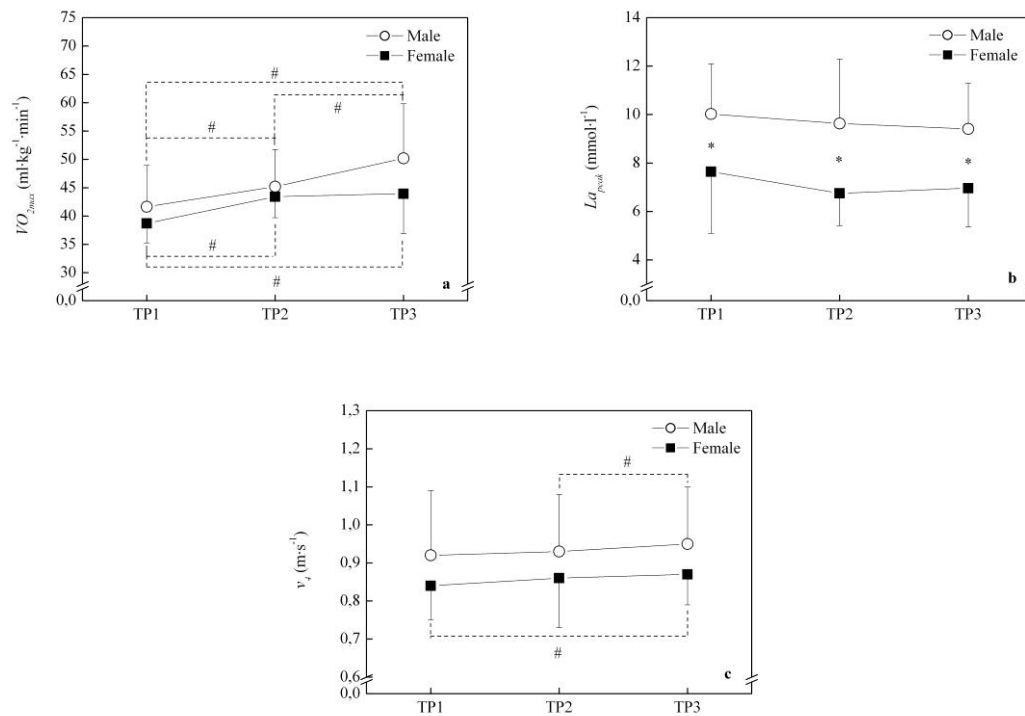


Figure 2. Mean±SD values of VO_{2max} (a), La_{peak} (b) and v_4 (c) in the three TPs. (*) significant differences in La_{peak} between males and females (TP₁: $p=0.02$; TP₂: $p<0.001$; TP₃: $p<0.001$). # significant differences in v_4 male between TP₂-TP₃ ($p=0.02$) and female between TP₁-TP₃ ($p=0.02$); in VO_{2max} male between TP₁-TP₂ ($p=0.01$), TP₂-TP₃ ($p=0.01$) and TP₁-TP₃ ($p<0.001$); and VO_{2max} female TP₁-TP₂ ($p=0.01$), and TP₁-TP₃ ($p=0.02$).

Biomechanics. Males presented a higher SF only in TP₁ (Figure 3). In the other two TPs, females obtained a higher SF , although these differences were not significant, with a small effect size over the season (TP₁: $\eta_p^2=0.04$; TP₂: $\eta_p^2=0.17$; TP₃: $\eta_p^2=0.11$). In females, SF decreased between TP₁-TP₂ (-1.9%; $p=0.04$), increased between TP₂-TP₃ (2.2%) and between TP₁-TP₃ (0.3%). In males a non-significant decrease was observed throughout the season: -8.6%, -0.5% and -9.1% (Figure 3a). SL was higher in males compared to females in all TPs (TP₁: $p=0.04$; TP₂: $p<0.001$; TP₃: $p<0.001$) with a moderate and large effect in TP₂ ($\eta_p^2=0.29$) and TP₃ ($\eta_p^2=0.37$), respectively (Figure 3b). In both genders, SL increased from TP₁-TP₂ (male: 7.7%; female: $p<0.001$; 6.0%) and slightly decreased from TP₂-TP₃ (male: -1.5%; female: -0.7%). From the first to the last TP, SL increased 6.1% in male and 5.2% in female group ($p=0.03$).

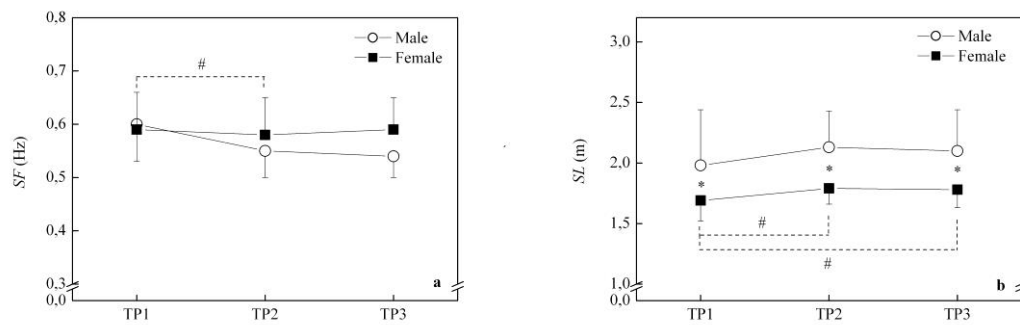


Figure 3. Mean±SD values of *SF* (a) and *SL* (b) in the three TPs. (*) significant differences in *SL* between males and females (TP₁: $p=0.04$; TP₂: $p<0.001$; TP₃: $p<0.001$); # significant differences in females *SL* between TP₁-TP₂ ($p<0.001$) and TP₁-TP₃ ($p=0.03$).

Males presented a higher *SI* and η_p than females in all TPs (Figure 4). However, these gender differences were only significant for *SI* in TP₁ ($p=0.01$) and TP₂ ($p<0.001$), with a moderate-sized effect in TP₂ ($\eta_p^2=0.25$). In males, a non-significant increase was observed in *SI* throughout the season: 5.8%, 1.1% and 6.9%. In females, *SI* presented an increase between TP₁-TP₂ (9.5%; $p=0.04$), TP₂-TP₃ (1.0%) and between TP₁-TP₃ (10.6%; $p=0.03$) (Figure 4a). Non-significant differences were found in η_p between genders in all TPs (Figure 4b). In both genders, η_p increased from TP₁-TP₂ (male: 8.9%, $p=0.01$; female: 5.8%, $p=0.01$), decreasing slightly from TP₂-TP₃ (male: -0.8%; female: -0.5%).

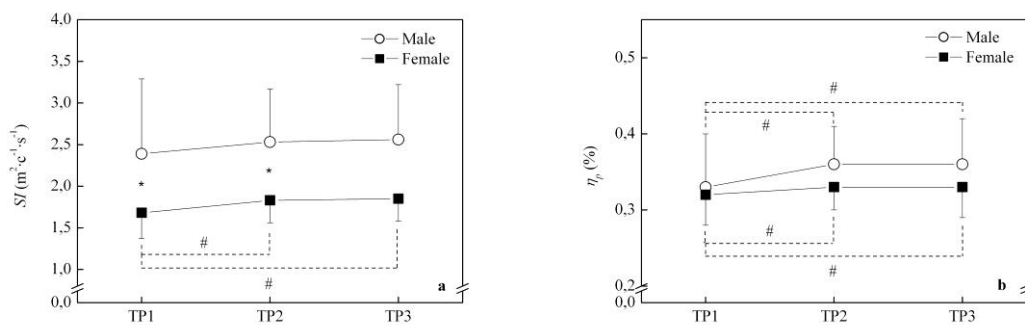


Figure 4. Mean±SD values of *SI* (a) and η_p (b) in the three TPs. (*) significant differences in *SI* between males and females (TP₁: $p=0.01$; TP₂: $p<0.001$). # significant differences in female *SI* between TP₁-TP₂ ($p<0.001$) and TP₁-TP₃ ($p<0.001$); in male η_p between TP₁-TP₂ ($p=0.01$) and TP₁-TP₃ ($p=0.02$) and in female η_p between TP₁-TP₂ ($p=0.01$) and TP₁-TP₃ ($p=0.03$).

In TP₁ we found non-significant effect of gender on biomechanic variables. In TP₂ the gender influence was greater in *SL*, followed by *SI*, both with a medium-size effect ($\eta_p^2=0.29$ $p=0.01$, and $\eta_p^2=0.26$ $p=0.02$, respectively). TP₃ presented a significant large effect-sized in *SL* ($\eta_p^2=0.37$).

Performance. Comparing both genders, males had always better performances than females (TP₁: $p=0.02$, $\eta_p^2=0.11$; TP₂: $p=0.04$, $\eta_p^2=0.02$; TP₃: $p=0.01$, $\eta_p^2=0.03$). The males presented a non-significant improvement in the performance over the season (TP₁-TP₂: -1.5%; TP₂-TP₃: -2.0%; TP₁-TP₃: -3.5%) while, in females, significant improvements were observed in TP₁-TP₂ (-3.8%; $p<0.001$) and TP₁-TP₃ (-5.7%; $p<0.001$) (Figure 5).

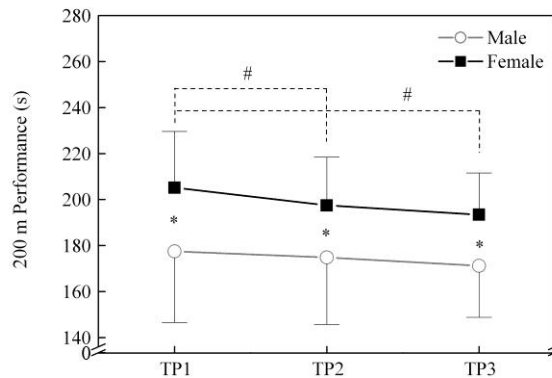


Figure 5. Mean \pm SD values of the 200 m freestyle performance in the three TPs. (*) significant differences between genders (TP₁: $p=0.02$; TP₂: $p=0.04$; TP₃: $p=0.01$). (#) significant differences in female 200 m performance between TP₁-TP₂ ($p<0.001$); TP₁-TP₃ ($p<0.001$).

Performance determinants. A large effect of SF , SL , SI and η_p on performance in the three TPs was found. In TP₁ a moderate-sized effect of SF ($\eta_p^2=0.24$, $p=0.04$) and η_p ($\eta_p^2=0.28$, $p=0.03$), a large effect of SL ($\eta_p^2=0.46$, $p<0.001$) and SI ($p<0.001$, $\eta_p^2=0.78$). In TP₂ a large effect of SI ($\eta_p^2=0.37$, $p=0.01$). In TP₃ a large effect of SI ($\eta_p^2=0.32$, $p=0.01$) was found. Concerning the effect of energetic variables on performance, a moderate-sized effect of v_4 on performance was found ($\eta_p^2=0.23$, $p=0.04$) in TP₃. There was a non-significant effect of gender on performance over the season.

Discussion

The aims of this study were to compare the changes in performance, energetics and biomechanics of male and female master swimmers and to analyze the effect of the energetic variables and gender on performance and biomechanical variables within a season. Males presented better performances and higher values of SL , SI and La_{peak} than females. No differences between genders were found in SF , η_p , v_4 and VO_{2max} . SF , SL , SI , η_p and v_4 influence the performance.

Energetics. The glycolytic metabolism depends on muscle mass involved, such as on the proportion of fast-twitch fibres (Benelli *et al.*, 2007). With men having greater skeletal muscle mass than women, it is expected higher lactate production, and the large effect of gender on La_{peak} found in TP₃ emphasizes that difference. No-significant increase in La_{peak} was found throughout the season in

both genders. The assessment of $L_{a_{peak}}$ is related to anaerobic capacity and the absence of improvements is probably due to the lower percentage of anaerobic workout and to the decrease found in anaerobic capacity with ageing (Reaburn and Dascombe, 2009). The values reported in both genders were lower than those obtained by Benneli et al. (2007) ($10.8 \pm 2.8 \text{ mmol} \cdot \text{l}^{-1}$ in female, and $14.2 \pm 2.5 \text{ mmol} \cdot \text{l}^{-1}$ in male). This could be because of the different experiences and performance level of our sample, including from elite swimmers to “weekend athletes” who sporadically train and compete.

The v_4 is influenced by the volume of training: higher training volume leads to greater aerobic capacity. Therefore, and since the training stimulus is the same for both genders, the absence of differences between male and female is not surprising. Generally, the increase in v_4 happens in the first months of training due to volume increase. On the other hand, our sample was engaged in a high percentage of aerobic training pace throughout the season. The increase in VO_{2max} for both genders may be due to that training, with a minor focus on strength, speed, and power tasks as occurs in young and elite swimmers (Weir *et al.*, 2002). The v_4 has a large effect on performance and in biomechanics variables, being the effect size higher in SI , followed by η_p and SL . Considering that the assessment of v_4 is important in determining the aerobic capacity of the swimmers, the higher influence of v_4 on performance highlights the importance of aerobic contribution for the total energy expenditure in the 200 m race. The large effect found of v_4 on SI , SL and η_p , may be caused by the aerobic loads, that allows to swim at low velocities and focus on technical aspects of the stroke mechanics, improving their technical ability.

Biomechanics. Females presented non-significant higher values of SF than males in TP_2 and TP_3 . SF is dependent of the limb’s kinematics (Barbosa *et al.*, 2011) and the surface area of propulsive segments (Pelayo *et al.*, 1996). A negative non significant relationship between SF and arm span was found in another study (Santos, 1998). However, these gender differences in SF were non-significant, which was corroborated by the absence of a significantly effect-sized of gender on SF in the three TP. Female swimmers presented a decrease in SF between TP_1 - TP_2 which may be related with training. The swimmers may have learned how to swim with fewer strokes and to be more effective as demonstrated by the improvement found in η_p over the season. Comparing with Zamparo’s data (Zamparo, 2006), the difference found may be due the different methodology used to calculate SF . Zamparo used the average time taken to complete five strokes, while we used the average time to complete three strokes (Zamparo, 2006).

The SL is related with the anthropometric characteristics, e.g. height, arm span and arm length. In our study, male were taller than female, whereby the greater SL of males may be related with their anthropometric values. Moreover, SL is related to the ability to exert powerful and effective stroke in water. The power developed per cycle by males is higher than females because the latter have less muscle strength and power (Macaluso and Vito, 2004), in opposition to the higher muscle mass in males (Doherty, 2001).

Female SL increased from TP_1 - TP_2 and TP_1 - TP_3 which would mean that, with training, the stroke became more powerful and effective and probably contributed to the improved performance. Zamparo's results (Zamparo, 2006) were different, with males reaching lower values of SL and females presenting higher values than ours, possibly because of the different anthropometrics and test performed. The higher SF and lower SL found by Favaro and Lima (2005) may be due to the different race used (50 m). In shorter distances, v increases at expense of the increase of SF and not SL . Knowing that SL is larger at a slow velocity and tends to decrease at maximal velocity values (Zamparo, 2006) and analysing the results of Zamparo *et al.* (2012a) the lower SF values and higher SL were probably due to the different test used where v was achieved by a smaller SF and a larger SL .

The anthropometrics, specifically the height, could also influence the higher SI values presented by male swimmers. These results were highlighted by the moderate effect of gender on SL and SI . Females presented an increase in SI throughout the season, that represented an improvement in the ability to swim higher distances within a stroke cycle at similar velocities (Costill *et al.*, 1985). The absence of significant increase in male SI (and SL) probably means that male presented a better swim technique compared to women, being more difficult to observe changes in stroke mechanics.

The η_p was higher (no-significant) in males compared to females in all TPs. As indicated by equation 1, η_p is directly related with v and inversely related with SF . Since males presented better performances than females these results are expected. Moreover, the results revealed that females obtained higher (non-significant) values of SF than males in two periods of the season (TP_2 and TP_3), which may also justify the higher values of η_p found in males. The different values obtained by Zamparo (2006) could be attributed to the anthropometric characteristics of the subjects, as a shorter shoulder-to-hand distance lead to higher η_p : the swimmers of our study presented lower values of arm length compared to the Zamparo's study ($0.60 \pm 0.03m$ and $0.57 \pm 0.01m$ vs. $0.73 \pm 0.06m$, respectively).

Performance. Differences in the 200 m performance between genders may be attributed to both energetic and biomechanics factors. The energetics focuses on the ability of the muscle cells to provide energy by three distinct, but operating together, metabolic pathways (aerobic, anaerobic lactic and anaerobic alactic)(Gastin, 2001). The contribution of each one to release energy for competitive swimming depends on the exercise intensity and duration. The main energy source for the 200 m is aerobic, followed by the anaerobic lactic system. La_{peak} , as a measure of anaerobic energy release during exercise, suggest a higher anaerobic contribution in the male group compared to females. Regarding the biomechanics, the higher values of SL , SI and η_p in males may ascribe the better performance compared to female.

Swimming performance depends on the interaction between physiological and biomechanical factors (Barbosa *et al.*, 2010) and therefore, the improvement in female swimmers from TP_1 - TP_2 and TP_1 -

TP₃ may be due to the variations in those variables over the season. The influence that the technical aspects had on performance rather the energetics may be a consequence of the structural and functional impairment that occurs with advancing age in most physiological systems (Bongard *et al.*, 2007), associated to the minor engaging in regular exercise (DiPietro, 2001) and the characteristics of training (predominantly aerobic). Thus, it seems that, in this age-group, the swimming technique is the major determinant for performance.

It can be pointed as main limitations of the study: (i) the subjects performed-oriented instead of fitness-oriented; (ii) the slightly effects in middle aged swimmers (compared to advanced ages); (iii) the no-use of more sophisticated biomechanical analysis (i.e. videometry), since it was too time consuming and complex to be conducted.

Conclusions

Men had better performances, SL , SI and La_{peak} than women. Contrary to males, female masters swimmers improved significantly their 200 m freestyle performance over a season of training due the improvement in swimming technique (SL , SI and η_p), v_4 and VO_{2max} . Gender had a significant effect on SL , SI and La_{peak} , which could mean that the performance is more dependent on technical factors than energetic aspects.

Practical Applications

In this age-group, the performance seems to be more dependent on technical than energy factors whereby, the training should aim to preserve the energetic factors as much as possible and, at the same time, develop the technical skills.

Chapter 4 - General Discussion

The main aim of this thesis was to conduct a longitudinal assessment of performance, energetics, and biomechanics of masters swimmers and understand the interplay between these domains over one full season. There were no longitudinal studies related with changes in the performance and the factors that influence it in masters swimmers within and between seasons. In a 200 m, Aer was the major partial contributor to E_{tot} in both genders, and an improvement in aerobic capacity was found throughout the season. The enhancement of performance found in this age-group over a season seems to be more dependent on technical than energetic factors, having been found the improvement of swimming technique in the first months of training. However, each swimmer used an individual strategy, combining SF and SL , to reach higher performances. Gender has a significant effect on SL , SI and La_{peak} , but not in performance, with men presenting higher values than women.

At the beginning of the thesis, a systematic review based on the papers published on energetics, biomechanics, and performance in masters swimmers was carried out (chapter 2, study 1). Our first conclusion was that few studies related to masters swimmers are found in the literature, the reason why we considered, in addition to longitudinal, cross-sectional studies in the review. Furthermore, most of the papers analyzed presented low quality scores compared to studies in health and social sciences fields. This may be related to the fact that in this field, some procedures are not performed due to human and material constraints, such as the availability of subjects to participate in studies and the challenges imposed by the environment where the activities are taken place, making the use of some equipment hard. After this systematic review, we found that there was a gap and some topics remained unanswered, such as: how does performance, energetic, and biomechanics improve over a season in masters swimmers; what are the differences between genders regarding energetics and biomechanics profile, and performance. Thus, to try to fill this gap, three experimental studies were conducted.

During a season, swimmers are submitted to a training process which is developed to enhance both energetics and biomechanics profiles. Therefore, to assess the changes that may occur over a season, the same swimmers were evaluated at three different times, to learn if training influences or not, the parameters monitored. In the first study, the analysis of the energetics factors that may affect performance showed that the aerobic capacity (v_4 and VO_{2max}) of the swimmers improved throughout the season, unlike what was found with anaerobic capacity (La_{peak}). Since there are no studies that analyze this topic over a season, for benchmark purposes we considered as reference studies conducted with young/elite swimmers. Thus, in young and elite swimmers, most gains in aerobic capacity occur in the early months of the beginning of the season, whereas in masters swimmers it was found a significant increase from the first to the last TP. This was as result to the higher prevalence of aerobic workout during their training throughout the season (and not only at

the beginning of the season), at the expense of strength, speed, and power that occurs in young and elite swimmers (Weir *et al.*, 2002). Regarding the biomechanics, results showed that each swimmer selected an individual strategy. Specific adaptations in biomechanics variables within the season through different combinations of SF and SL , suggesting that SF and SL modifications in stroke parameters were individual (Huot-Marchand *et al.*, 2005). In the first months of the training season, there was an improvement in SL . From mid phases until the end of the season, SF also played a role on performance. Thus, considering studies conducted with elite swimmers, these different combinations for SF and SL were also observed in different swimmers (Costa *et al.*, 2012b). That said, it seems that, in this age-group, the performance is more dependent on technical than energetic factors.

After analyzing the changes of the factors affecting the performance over the season, we tried to answer the following question: have the same training load different effects in men and women? To answer such question, a third and fourth studies were designed. Main findings were that the main energetic pathway seems to be different in men and women, being La_{peak} and VO_{2max} higher in males compared to females (study 3 and 4). Regarding biomechanics parameters (study 4), the notorious and well documented difference in anthropometrics traits between males and females may explain some differences found between genders, such as height, arm span and arm length (Zamparo, 2006).

Swimming performance is dependent on the interplay between energetics and biomechanics parameters (Barbosa *et al.*, 2010). Thus, after discussing the changes that occurred in those parameters, their influence in performance will be discussed. The positive relationship found between the increase of both v_{200} and SF suggests the importance of SF on performance. However, the absence of significant correlation between changes in v_{200} and energetic variables could mean that, in this age-group, the performance is more dependent on technical than energetic factors, amid the decline in maximal metabolic power (aerobic and anaerobic) that is an inevitable over the life span.

Some main limitation can be addressed to this thesis: i) heterogeneity of the sample, which included former swimmers with participations in national championships when they were young plus subjects that started competing for the very first time more recently being till then fitness-oriented swimmers; (ii) the moderate effects in middle aged swimmers (compared to advanced ages); (iii) the selection of straightforward and quick procedures to perform the kinematic analysis, rather than more cutting edge-procedures (e.g. motion capture systems) since the last ones are too time-consuming and complex to be conducted in a thesis with this scope.

Chapter 5 - Overall Conclusions

The main findings of this thesis were:

- i) Study 1: Cross-sectional studies related with energetics, biomechanics, and performance in masters swimmers are scarce and present low quality scores;
- ii) Study 2: Masters swimmers improved significantly their 200m freestyle performance over a season. Each swimmer used an individual strategy, combining SF and SL , to reach higher performances throughout the season. In this age-group the performance seems to be more dependent on technical than energetic factors.
- iii) Study 3: Aer was the major contributor for E_{tot} in both genders; male swimmers present higher Aer , AnL and $AnAl$ contributions than female.
- iv) Study 4: Female masters swimmers significantly enhanced the 200m freestyle performance over a season due to the improvement in swimming technique (SL , SI and η_p) and energetics (v_4 and VO_{2max}). Gender has a significant effect on SL , SI and La_{peak} .

In summary, it was found that, in this age-group, performance improved over a season. Despite improvements in the energetics over the season, performance is more dependent on technical than energetic factors. Therefore, training with masters swimmers should aim to keep or if possible build-up energetic factors as much as possible and, on top of that, enhance the technic.

Chapter 6 - Suggestions for Future Research

Some suggestions are highlighted in order to encourage future research:

- i. Spin-off this thesis and compare different cohort groups (former swimmers vs. “recent” swimmers);
- ii. Spin-off this thesis to a research design that monitors the swimmers over a longer period of time (e.g. two or more seasons);
- iii. If feasible, select cutting-edge biomechanic analysis (i.e. motion capture systems) and/or add the monitoring of the hydrodynamic profile as well as some physiological parameters related to health (e.g., hematology, endocrine secretion, muscle biochemistry)

Chapter 7 - References

- Anderson, M. E., Hopkins, W. G., Roberts, A. D., and Pyne, D. B. (2006). Monitoring seasonal and long-term changes in test performance in elite swimmers. *European Journal of Sport Science*, 6, 145-154.
- Aniansson, A., Grimby, G., Hedberg, M., and Krotkiewski, M. (1981). Muscle morphology, enzyme activity and muscle strength in elderly men and women. *Clinical Physiology*, 1(1), 73-86.
- Barbosa, T. M., Bragada, J. A., Reis, V. M., Marinho, D. A., Carvalho, C., and Silva, A. J. (2010). Energetics and biomechanics as determining factors of swimming performance: updating the state of the art. *Journal of Science and Medicine in Sport / Sports Medicine Australia*, 13(2), 262-269.
- Barbosa, T. M., Marinho, D. A., Costa, M. J., and Silva, A. J. (2011). Biomechanics of Competitive Swimming Strokes. In *Biomechanics in Applications* (pp. 367-388).
- Benelli, P., Ditroilo, M., Forte, R., De Vito, G., and Stocchi, V. (2007). Assessment of post-competition peak blood lactate in male and female master swimmers aged 40-79 years and its relationship with swimming performance. *European Journal of Applied Physiology*, 99(6), 685-693.
- Binzoni, T., Ferretti, G., Schenker, K., and Cerretelli, P. (1992). Phosphocreatine hydrolysis by ³¹P-NMR at the onset of constant-load exercise in humans. *Journal of Applied Physiology*, 73(4), 1644-1649.
- Bongard, V., McDermott, A. Y., Dallal, G. E., and Schaefer, E. J. (2007). Effects of age and gender on physical performance. *Age*, 29(2-3), 77-85.
- Bortz IV, W. M., and Bortz II, W. M. (1996). How fast do we age? Exercise performance over time as a biomarker. *Journal of Gerontology Biological Sciences and Medical Sciences*, 51A(5), M223-225.
- Buskirk, E. R., and Hodgson, J. L. (1987). Age and aerobic power: the rate of change in men and women. *Federation Proceedings*, 46, 1824-1829.
- Capelli, C., Pendergast, D. R., and Termin, B. (1998). Energetics of swimming at maximal speeds in humans. *European Journal of Applied Physiology and Occupational Physiology*, 78(5), 385-393.
- Cohen, J. (1988). *Statistical Power Analysis for the Behavioral Sciences*. (N. Hillsdale, Ed.) (2nd Editio., p. 567). Lawrence Earlbaum Associates.
- Costa, M. J., Bragada, J. A., Marinho, D. A., Silva, A. J., and Barbosa, T. M. (2012a). Longitudinal interventions in elite swimmers: a systematic review based on energetics, biomechanics, and performance. *Journal of Strength and Conditioning Research*, 26(7), 2006-2016.
- Costa, M. J., Bragada, J. A., Mejias, J. E., Louro, H., Marinho, D. A., Silva, A. J., and Barbosa, T. M. (2012b). Tracking the performance, energetics and biomechanics of international versus national level swimmers during a competitive season. *European Journal of Applied Physiology*, 112, 811-820.

- Costa, M. J., Bragada, J. A., Mejias, J. E., Louro, H., Marinho, D. A., Silva, A. J., and Barbosa, T. M. (2013). Effects of swim training on energetics and performance. *International Journal of Sports Medicine*, 34(6), 507-513.
- Costa, M. J., Marinho, D. A., Reis, V. M., Silva, A. J., Marques, M. C., Bragada, J. A., and Barbosa, T. M. (2010). Tracking the performance of world-ranked swimmers. *Journal of Sports Science and Medicine*, 9(3), 411-417.
- Costill, D. L., Kovaleski, J., Porter, D., Kirwan, J., Fielding, R., and King, D. (1985). Energy expenditure during front crawl swimming: predicting success in middle-distance events. *International Journal Sports Medicine*, 6(5), 266-70.
- Costill, D. L., Thomas, R., Robergs, R. A., Pascoe, D., Lambert, C., Barr, S., and Fink, W. J. (1991). Adaptations to swimming training: influence of training volume. *Medicine and Science in Sports and Exercise*, 23(3), 371-377.
- Coyle, E. F. (1995). Integration of the physiological factors determining endurance performance ability. *Exercise Sports Sciences Reviews*, 23, 25-63.
- Craig, A., Skehan, P., Pawelczyk, J., and Boomer, W. (1985). Velocity, stroke rate, and distance per stroke during elite swimming competition. *Medicine and Science in Sports and Exercise*, 17(6), 625-634.
- Daly, D. J., and Vanlandewijck, Y. (1999). Some Criteria for Evaluating the "Fairness" of Swimming Classification. *Adapted Physical Activity Quarterly*, 16, 271-289.
- Di Prampero, P. E., and Ferretti, G. (1999). The energetics of anaerobic muscle metabolism: a reappraisal of older and recent concepts. *Respiration Physiology*, 118(2-3), 103-115.
- DiPietro, L. (2001). Physical activity in aging: changes in patterns and their relationship to health and function. *The Journals of Gerontology. Series A, Biological Sciences and Medical Sciences*, 56, 13-22.
- Doherty, T. J. (2001). The influence of aging and sex on skeletal muscle mass and strength. *Current Opinion in Clinical Nutrition and Metabolic Care*, 4(6), 503-508.
- Donato, A. J., Tench, K., Glueck, D. H., Seals, D. R., Eskurza, I., and Tanaka, H. (2003). Declines in physiological functional capacity with age: a longitudinal study in peak swimming performance. *Journal of Applied Physiology*, 94(2), 764-769.
- Downs, S. H., and Black, N. (1998). The feasibility of creating a checklist for the assessment of the methodological quality both of randomised and non-randomised studies of health care interventions. *Journal of Epidemiology and Community Health*, 52(6), 377-84.
- Eskurza, I., Donato, A. J., Moreau, K. L., Seals, D. R., and Tanaka, H. (2002). Changes in maximal aerobic capacity with age in endurance-trained women: 7-yr follow-up. *Journal of Applied Physiology*, 92(6), 2303-2308.
- Faulkner, A. J., Larkin, L. M., Claflin, D. R., and Brooks, S. V. (2007). Age-related changes in the structure and function of skeletal muscles. *Clinical and Experimental Pharmacology & Physiology*, 34(11), 1091-6.
- Favaro, O., and Lima, F. T. (2005). Influence of the age in the performance, stroke rate and stroke length in masters male swimmers of the 50 meters freestyle. *Brazilian Journal of Science and Movement*, 13(3), 67-72.

- Figueiredo, P., Zamparo, P., Sousa, A., Vilas-Boas, J. P., and Fernandes, R. J. (2011). An energy balance of the 200 m front crawl race. *European Journal of Applied Physiology*, 111(5), 767-777.
- Fitzgerald, M. D., Tanaka, H., Tran, Z. V., and Seals, D. R. (1997). Age-related declines in maximal aerobic capacity in regularly exercising vs. sedentary women: a meta-analysis. *Journal of Applied Physiology*, 83, 160-165.
- Fleg, J. L., Morrell, C. H., Bos, A. G., Brant, L. J., Talbot, L., Wright, J. G., and Lakatta, E. G. (2005). Accelerated longitudinal decline of aerobic capacity in healthy older adults. *Circulation*, 112(5), 674-82.
- Gastin, P. B. (2001). Energy system interaction and relative contribution during maximal exercise. *Sports Medicine*, 31(10), 725-741.
- Gatta, G., Benelli, P., and Ditroilo, M. (2006). The decline of swimming performance with advancing age: a cross-sectional study. *Journal of Strength and Conditioning Research*, 20(4), 932-938.
- Hagberg, J. M. (1987). Effect of training on the decline of VO₂max with aging. *Federation Proceedings*, 46(5), 1830-1833.
- Hastings, D., Kurth, S., Schloder, M., and Cyr, D. (1995). Reasons for Participating in a Serious Leisure Career: Comparison of Canadian and U.S. Masters Swimmers. *International Review for the Sociology of Sport*, 30, 101-119.
- Hawkins, S., and Wiswell, R. (2003). Rate and mechanism of maximal oxygen consumption decline with aging: implications for exercise training. *Sports Medicine*, 33(12), 877-888.
- Huot-Marchand, F., Nesi, X., Sidney, M., Alberty, M., and Pelayo, P. (2005). Variations of stroking parameters associated with 200 m competitive performance improvement in top-standard front crawl swimmers. *Sports Biomechanics*, 4(1), 89-99.
- Janssen, I., Heymsfield, S. B., Wang, Z., and Ross, R. (2000). Skeletal muscle mass and distribution in 468 men and women aged 18 – 88 yr. *Journal of Applied Physiology*, 89, 81-88.
- Jaworowski, A., Porter, M. M., Holmbäck, A. M., Downham, D., and Lexell, J. (2002). Enzyme activities in the tibialis anterior muscle of young moderately active men and women: relationship with body composition, muscle cross-sectional area and fibre type composition. *Acta Physiologica Scandinavica*, 176(3), 215-225.
- Jensen-Urstad, M., Svedenhag, J., and Sahlin, K. (1994). Effect of muscle mass on lactate formation during exercise in humans. *European Journal of Applied Physiology and Occupational Physiology*, 69(3), 189-195.
- Katzel, L. I., Sorkin, J. D., and Fleg, J. L. (2001). A Comparison of Longitudinal Changes in Aerobic Fitness in Older Endurance Athletes and Sedentary Men. *Journal of the American Geriatrics Society*, 49(12), 1657-1664.
- Korhonen, M. T., Suominen, H., and Mero, A. (2005). Age and sex differences in blood lactate response to sprint running in elite master athletes. *Canadian Journal of Applied Physiology*, 30(6), 647-665.
- Laffite, L. P., Vilas-Boas, J. P., Demarle, A., Silva, J., Fernandes, R., and Billat, V. L. (2004). Changes in physiological and stroke parameters during a maximal 400-m free swimming test in elite swimmers. *Canadian Journal of Applied Physiology*, 29(S1), S17-S31.

- Landis, J. R., and Koch, G. G. (1977). The measurement of observer agreement for categorical data. *Biometrics*, 33, 159-174.
- Lavoie, J. M., and Montpetit, R. R. (1986). Applied physiology of swimming. *Sports Medicine*.3(3):165-89, Jun.
- Macaluso, A., and Vito, G. (2004). Muscle strength, power and adaptations to resistance training in older people. *European Journal of Applied Physiology*, 91(4), 450-472.
- Maglischo, E. (2003). *Swimming Fastest*. Champaign: Human Kinetics Books.
- Maharam, L. G., Bauman, P. A., Kalman, D., Skolnik, H., and Perle, S. M. (1999). Masters athletes: factors affecting performance. / Athletes veterans: les facteurs affectant la performance. *Sports Medicine*, 28(4), 273-285.
- Maron, B. J., Araújo, C. G. S., Thompson, P. D., Fletcher, G. F., Luna, A. B. de, Fleg, J. L., Pelliccia, A., Balady, G. J., Furlanello, F., Camp, S. P. Van, Elosua, R., Chaitman, B. R., Bazzarre, and T. L., Camp, S. P., Van Elosua, R., Chaitman, B. R., and Bazzarre, T. L. (2001). Recommendations for Preparticipation Screening and the Assessment of Cardiovascular Disease in Masters Athletes. *Circulation*, 103(2), 327-334.
- McGlynn, G. (1996). *Dynamics of Fitness: A Practical Approach* (4th Editio.). Brown & Benchmark (Madison Wis.).
- McGowan, J., and Sampson, M. (2005). Systematic reviews need systematic searchers. *Journal of the Medical Library Association*, 93(1), 74-80.
- Mejias, J. E., Bragada, J. A., Costa, M. J., Reis, V. M., Garrido, N. D., and Barbosa, T. M. (2014). "Young" masters vs. elite swimmers: comparison of performance, energetics, kinematics and efficiency. *International SportMed Journal*, 15(2), 165-177.
- Morais, J. E., Garrido, N. D., Marques, M. C., Silva, A. J., Marinho, D. A., and Barbosa, T. M. (2013). The influence of anthropometric, kinematic and energetic variables and gender on swimming performance in youth athletes. *Journal of Human Kinetics*, 39, 203-211.
- Ogawa, T., Spina, R. J., Martin, W. H., Kohrt, W. M., Schechtman, K. B., Holloszy, J. O., and Ehsani, a. a. (1992). Effects of aging, sex, and physical training on cardiovascular responses to exercise. *Circulation*, 86(2), 494-503.
- Pelayo, P., Sidney, M., Kherif, T., Chollet, D., and Tourny, C. (1996). Stroking Characteristics in Freestyle Swimming and Relationship With Anthropometric Characteristics. *Journal of Applied Biomechanics*, 12, 197-206.
- Pendergast, D. R., Capelli, C., Minetti, A. E., and Mollendorf, J. (2006). Biophysics in swimming. *Revista Portuguesa de Ciências Do Desporto*, 6(23), 185-189.
- Pendergast, D. R., and Zamparo, P. (2011). Balance of Biomechanical and Physiological Contributions to Swimming Performance. *Portuguese Journal of Sport Sciences*, 11(Suppl 3), 51-59.
- Porter, M. M., Vandervoort, A. A., and Lexell, J. (1995). Aging of human muscle: structure, function and adaptability. *Scandinavian Journal of Medicine and Science in Sports*, 5, 129-142.
- Pyne, D. B., Lee, H., and Swanwick, K. M. (2001). Monitoring the lactate threshold in world-ranked swimmers. *Medicine and Science in Sports and Exercise*, 33, 291-297.

- Pyne, D., Trewin, C., and Hopkins, W. (2004). Progression and variability of competitive performance of Olympic swimmers. *Journal of Sports Sciences*, 22, 613-620.
- Ransdell, L. B., Vener, J., and Huberty, J. (2009). Masters athletes: an analysis of running, swimming and cycling performance by age and gender. *Journal of Exercise Science & Fitness*, 7(2), 61-73.
- Ransdell, L. B., and Wells, C. L. (1999). Sex Differences in Athletic Performance. *Women in Sport & Physical Activity Journal*, 8, 55.
- Reaburn, P., and Dascombe, B. (2009). Anaerobic performance in masters athletes. *European Review of Aging and Physical Activity*, 6(1), 39-53.
- Reaburn, P., and Mackinnon, L. T. (1990). Blood lactate responses in older swimmers during active and passive recovery following maximal sprint swimming. *European Journal of Applied Physiology and Occupational Physiology*, 61(3-4), 246-250.
- Rodríguez, F. A. (2000). Maximal oxygen uptake and cardiorespiratory response to maximal 400-m free swimming, running and cycling tests in competitive swimmers. *Journal of Sports Medicine and Physical Fitness*, 40(2), 87-95.
- Rubin, R. T., Lin, S., Curtis, A., Auerbach, D., and Win, C. (2013). Declines in swimming performance with age: a longitudinal study of Masters swimming champions. *Open Access Journal of Sports Medicine*, 4, 63-70.
- Rubin, R. T., and Rahe, R. H. (2010). Effects of aging in Masters swimmers: 40-year review and suggestions for optimal health benefits. *Open Access Journal of Sports Medicine*, 1, 39-44.
- Rüst, C. A., Knechtle, B., and Rosemann, T. (2012). Women achieve peak freestyle swim speed at earlier ages than men. *Open Access Journal of Sports Medicine*, 3, 189-99.
- Ryan, R., Coyle, E., and Quick, R. (1990). Blood lactate profile throughout a training season in elite female swimmers. *Journal of Swimming Research*, 6(3), 5-10.
- Santos, S. (1998). Relationship among anthropometric characteristics, stroke frequency and stroke length in Brazilian elite swimmers. In VK-Universitätsverlag Konstanz (Ed.), *XVI International Symposium on Biomechanics in Sports* (pp. 251-254). Konstanz.
- Sharp, R. L., Vitelli, C. A., Costill, D. L., and Thomas, R. (1984). Comparison between blood lactate and heart rate profiles during a season of competitive swim training. *Journal of Swimming Research*, 1(1), 17-20.
- Sousa, A., Figueiredo, P., Zamparo, P., Vilas-Boas, J. P., and Fernandes, R. J. (2013). Anaerobic alactic energy assessment in middle distance swimming. *European Journal of Applied Physiology*, 113(8), 2153-2158.
- Tanaka, H., DeSousa, C. A., Jones, P. P., Stevenson, E. T., Davy, K. P., and Seals, D. R. (1997). Greater rate of decline in maximal aerobic capacity with age in physically active vs. sedentary healthy women. *Journal of Applied Physiology*, 83(6), 1947-1953.
- Tanaka, H., and Seals, D. R. (1997). Age and gender interactions in physiological functional capacity: insight from swimming performance. *Journal of Applied Physiology*, 82(3), 846-851.

- Tanaka, H., and Seals, D. R. (2003). Invited Review: Dynamic exercise performance in Masters athletes: insight into the effects of primary human aging on physiological functional capacity. *Journal of Applied Physiology*, 95(5), 2152-2162.
- Tanaka, H., and Seals, D. R. (2008). Endurance exercise performance in Masters athletes: age-associated changes and underlying physiological mechanisms. *The Journal of Physiology*, 586(1), 55-63.
- Tantrum, M., and Hodge, K. (1993). Motives for participating in masters swimming. *New Zealand Journal of Health, Physical Education and Recreation*, 26(1), 3-7.
- Termin, B., and Pendergast, D. R. (2000). Training using the stroke frequency-velocity relationship to combine biomechanical and metabolic paradigms. *The Journal of Swimming Research*, 14, 9-17.
- Thanopoulos, V. (2010). The 5 X 200 m step test lactate curve model: gender specific characteristics in elite Greek senior freestyle swimmers. *Serbian Journal of Sports Science*, 4(4), 153-160.
- Toussaint, H. M. (1990). Differences in propelling efficiency between competitive and triathlon swimmers. *Medicine and Science in Sports and Exercise*, 22(3), 409-15.
- Toussaint, H. M., and Hollander, A. P. (1994). Energetics of competitive swimming. Implications for training programmes. *Sports Medicine*, 18(6), 384-405.
- Weir, P. L., Kerr, T., Hodges, N. J., McKay, S. M., and Starkes, J. L. (2002). Master swimmers: How are they different from younger elite swimmers? An examination of practice and performance patterns. *Journal of Aging and Physical Activity*, 10(1), 41-63.
- Weiss, E. P., Spina, R. J., Holloszy, J. O., and Ehsan, A. A. (2006). Gender differences in the decline in aerobic capacity and its physiological determinants during the later decades of life. *Journal of Applied Physiology*, 101(3), 938-944.
- Wilmore, J. H. (1991). The aging of bone and muscle. *Clinical Sports Medicine*, 10(2), 231-244.
- Wilmore, J. H., and Costill, D. (2005). *Physiology and Sport and Exercise* (3rd Editio.). Human Kinetics Books.
- Zamparo, P. (2006). Effects of age and gender on the propelling efficiency of the arm stroke. *European Journal of Applied Physiology*, 97(1), 52-58.
- Zamparo, P., Capelli, C., Cautero, M., and Di Nino, A. (2000). Energy cost of front-crawl swimming at supra-maximal speeds and underwater torque in young swimmers. *European Journal of Applied Physiology*, 83(6), 487-491.
- Zamparo, P., Capelli, C., and Pendergast, D. (2011). Energetics of swimming: a historical perspective. *European Journal of Applied Physiology*, 111(3), 367-378.
- Zamparo, P., Gatta, G., Dall’Ora, A., Toneatto, A., and Cortes, M. (2012a). The determinants of performance in master swimmers: a cross-sectional study on the age-related changes in propelling efficiency, hydrodynamic position and energy cost of front crawl. *European Journal of Applied Physiology*, 112(12), 3949-3957.
- Zamparo, P., Gatta, G., and Prampero, P. E. (2012b). The determinants of performance in master swimmers: an analysis of master world records. *European Journal of Applied Physiology*, 112(10), 3511-3518.

- Zamparo, P., Pendergast, D. R., Mollendorf, J., Termin, A., and Minetti, A. E. (2005). An energy balance of front crawl. *European Journal of Applied Physiology*, 94(1-2), 134-144.
- Zamparo, P., Turri, E., Peterson Silveira, R., and Poli, A. (2014). The interplay between arms-only propelling efficiency, power output and speed in master swimmers. *European Journal of Applied Physiology*, 114(6), 1259-68.
- Zoeller, R. F., Nagle, E. F., Robertson, R. J., Moyna, N. M., Lephart, S. M., and Goss, F. L. (2000). Peak blood lactate and accumulated oxygen deficit as indices of freestyle swimming performance in trained adult female swimmers. *The Journal of Swimming Research*, 14, 18-25.