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Physiological and kinematic analysis of master swimmers 200 m front crawl

KEYWORDS:

Swimming. Performance.
Oxygen consumption.

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ABSTRACT

The aim of the present study was to (a) compare the physiological and kinematic variables of master swimmers during a maximal effort, and (b) correlate those variables with performance. Twenty-three swimmers, divided into three age groups, took part in the study: G1, 33.9 ± 1.7 ($n = 8$), G2, 44.7 ± 1.9 ($n = 8$) and G3, 59.4 ± 8.7 years old ($n = 7$). After measuring anthropometric characteristics, swimmers performed a 200 m front crawl maximal test. Oxygen consumption was continuously recorded and stroke rate and length, and swim speed were obtained using video analysis. Performance was 159.7 ± 11.7 (G1), 181.8 ± 20.8 (G2) and 211.0 ± 23.0 s (G3). Peak oxygen uptake was 52.5 ± 6.3 (G1), 47.3 ± 4.4 (G2) and 38.6 ± 5.5 (G3) ml.kg.min^{-1} , with age explaining 59% peak oxygen uptake variance. G3 had lower stroke length (1.64 ± 0.2 m) and stroke rate (33.0 ± 10.2 cycles.min^{-1}) compared to G1 (1.93 ± 0.14 m and 36.6 ± 3.6 cycles.min^{-1} , respectively). When all swimmers were analysed as a single group, there were inverse correlations between performance and stroke length ($r = -.72$; $p < .001$), stroke rate ($r = -.58$; $p = .003$), stroke index ($r = -.89$; $p < .001$) and peak oxygen uptake ($r = 0.81$; $p < .001$). As expected, both physiological and kinematic variables declined with age, leading to a reduction in swimming performance. Peak oxygen uptake and kinematic variables highly correlated with 200 m front crawl performance.

RESUMO

O presente estudo teve por objetivos (a) comparar variáveis fisiológicas e cinemáticas de nadadores masters durante um teste máximo, e (b) correlacioná-las com o desempenho desportivo. Vinte e três atletas, de três grupos etários participaram do estudo: G1: 33.9 ± 1.7 ($n = 8$); G2: 44.7 ± 1.9 ($n = 8$) e G3: 59.4 ± 8.7 anos de idade ($n = 7$). Após serem obtidas as medidas antropométricas, os nadadores realizaram um esforço máximo de 200 m nado crawl. O consumo de oxigênio foi continuamente registrado e a frequência e distância de ciclo, e velocidade de nado, obtidos por análise de vídeo. O desempenho foi de 159.7 ± 11.7 (G1), 181.8 ± 20.8 (G2) e 211.0 ± 23.0 s (G3). O pico do consumo de oxigênio foi de 52.5 ± 6.3 (G1), 47.3 ± 4.4 (G2) e 38.6 ± 5.5 ml.kg.min⁻¹ (G3), tendo a idade explicado 59% da variância do pico do consumo de oxigênio. O G3 obteve menores valores de distância (1.64 ± 0.2 m) e frequência de ciclo (33.0 ± 10.2 ciclos.min⁻¹) comparado ao G1 (1.93 ± 0.14 m e 36.6 ± 3.6 ciclos.min⁻¹, respectivamente). Quando todos os nadadores foram analisados como um grupo único, verificaram-se correlações inversas entre o desempenho e distância ($r = -.72$; $p < .001$) e frequência de ciclo ($r = -0.58$; $p = .003$), índice de nado ($r = -.89$; $p < .001$) e pico de consumo de oxigênio ($r = -.81$; $p < .001$). Como esperado, tanto as variáveis fisiológicas como as cinemáticas diminuíram com a idade, levando a uma redução no desempenho em natação. O pico de consumo de oxigênio e as variáveis cinemáticas apresentaram alta correlação com o desempenho em 200 m nado crawl.

PALAVRAS CHAVE:

Natação. Desempenho.

Consumo de oxigênio.

INTRODUCTION

Competitive swimming is composed by 50 to 1,500 m distances using four individual and combined (medley) swimming techniques (Pyne & Sharp, 2014). The front crawl, almost universally used during freestyle events, is considered the most traditional, fast and economical swimming technique (Barbosa et al., 2005). Master swimming engage experienced competitive swimmers and participants that began swimming in adulthood (Zamparo, Dall'ora, Toneatto, Cortesi, & Gatta, 2012), namely after 25 years of age (Fédération Internationale de Natation, 2017). Total participation numbers have consistently increased (Knechtle, Nikolaidis, Konig, Rosemann, & Rust, 2016), highlighting the importance of better understanding the relationship between swimming performance and ageing in this specific population. As reviewed by Tanaka and Seals (2003), swimming performance decreases in a curvilinear shape from 36 to 70 years and race time increases in an exponential manner. However, the decrease in swimming performance is 30% less compared to running, perhaps due to swimming dependency of biomechanical variables (Craig & Pendergast, 1979).

Swimmers displacement in the aquatic environment is dependent on final propulsion, obtained by subtracting drag (movement opposite force) from propulsive force. To generate more propulsive force, swimmers needs well-developed physiological characteristics and technical skills to generate propulsive force while reducing drag, to ultimately allow displacement with a low energy cost (Toussaint & Truijens, 2005). Additionally, drag is influenced by swimmers anthropometric and physical characteristics (Toussaint, Stralen, & Stevens, 2002).

Maximal oxygen consumption (O_{2max}) is used to evaluate physiological capability and is related to oxygen uptake, transport and use by the body, determining the upper limit for oxidative energy production (Poole & Jones, 2017). When it is not possible to observe a O_2 plateau, aerobic capability can be evaluated by the highest registered value (VO_{2peak} ; Ribeiro et al., 2015). Currently, it is possible to measure breath-by breath respiratory and pulmonary gas exchange using a portable gas analyser connected to the swimmer via a low hydrodynamic resistance respiratory snorkel and valve system (Baldari et al., 2013). This setup enables VO_2 data acquisition in conditions related with swimming practice and with a high sampling frequency, both of which allow monitoring VO_2 changes over a short time (Sousa et al., 2014). Moreover, swimming technique, and responses to different swimming constraints, are studied by kinematics, using variables as stroke length (SL, defined as the distance covered by the swimmer's body at each upper limb cycle) and stroke rate (SR, defined as the number of upper limb cycles per time unit). The product of SL and SR is swim speed (v), excluding start, turns, finish and streamline effects (Hay & Guimarães, 1983). Furthermore, the swimming index (SI, the product of SL and v) is an indicator of swimming economy (Costill et al., 1985).

The 200 m freestyle event has metabolic characteristics that include marked anaerobic and aerobic energy system participation, with performance being strongly influenced by

energy system interactions that alter swimming kinematic behaviour (Figueiredo, Pendergast, Vilas-Boas, & Fernandes, 2013). As the number of master swimmers is growing, studying this population will allow a better understanding about healthy ageing from a sports performance point of view. The present study compared $\text{VO}_{2\text{peak}}$, heart rate (HR), SR, SL, v and SI of master swimmers from different age groups during a maximal effort and related those variables with performance.

METHOD

Twenty-three male master swimmers volunteered to participate in this study and were divided into three groups according to the thirty-third and sixty-sixth age percentiles (group details are presented in Table 1). Swimmers who trained regularly over the past two years (swimming, at least, three times per week for a minimum of 2,000 m per day) and competed in the last year were included. Swimmers that did not trained for more than four weeks and presented injuries or sickness that could compromise the experiments were excluded. This study was approved by the local ethics committee and conducted according to the Declaration of Helsinki (1964).

TABLE 1. Mean $\pm$ SD and confidence interval values regarding anthropometric characteristics and FINA points of master swimmers.

	Group 1 (<i>n</i> = 8) 33.9 $\pm$ 1.7 years	Group 2 (<i>n</i> = 8) 44.7 $\pm$ 1.9 years	Group 3 (<i>n</i> = 7) 59.4 $\pm$ 8.7 years	<i>F</i> (<i>df</i>); <i>p</i> ; η^2
Body mass (kg)	77.8 $\pm$ 6.9]70.5 – 85.1[	80.1 $\pm$ 6.3]72.3 – 87.9[	76.6 $\pm$ 8.6]68.6 – 84.6[	<i>F</i> (2,18) = 0.60; <i>p</i> = .560; η^2 = .06
Height (cm)	180.9 $\pm$ 5.2]175.4 – 186.5[	176.9 $\pm$ 9.3]165.2 – 188.5[	175.7 $\pm$ 4.4]171.5 – 179.8[	<i>F</i> (2,18) = 1.72; <i>p</i> = .208; η^2 = .16
Body fat (%)	22.1 $\pm$ 5.4]16.3 – 27.8[	24.7 $\pm$ 4.8]18.6 – 30.8[	25.4 $\pm$ 3.4]22.2 – 28.5[	<i>F</i> (2,19) = 1.18; <i>p</i> = .330; η^2 = .11
Arm span (cm)	185.9 $\pm$ 4.6]181.1 – 190.8[	181.3 $\pm$ 10.1]168.7 – 194.0[	179.8 $\pm$ 5.5]174.7 – 185.0[	<i>F</i> (2,18) = 2.50; <i>p</i> = .110; η^2 = .21
FINA (points)	368.8 ^a $\pm$ 72.6]292.6 – 445.0[	228.0 ^b $\pm$ 76.2]133.3 $\pm$ 322.6[	197.5 ^b $\pm$ 51.5]149.8 – 245.2[	<i>F</i> (2,20) = 12.45; <i>p</i> < .001; η^2 = .55

Note: Different letters indicate groups difference, *p* < .05.

Swimmers anthropometrics and body composition measurements were obtained previously to the swimming test. Body mass (balance G-Tech Glass 200®, 150 kg capacity and 0.1 kg accuracy), height (portable stadiometer Cescorf®, 3 m capacity and 0.1 cm accuracy), upper arm span (anthropometric tape 3M, 2 m capacity and 0.1 cm accuracy) and fat mass (Dual-energy X-ray absorptiometry; Hologic Discovery W, EUA) were measured by an experienced researcher according to standard protocols. Participants were instructed not to exercise moderately or intensely (24 h), to drink alcohol (72 h) or to consume any

product with caffeine or calcium-based medications (24 h) without previous communication with the research team.

Participants filled out sociodemographic and training questionnaires that gave information about their best competition times during the previous year that, by transforming performance data into Fédération Internationale de Natation (FINA) points (<http://www.fina.org/content/fina-points>), allowed comparing competitive swimming levels (CF. TABLE 1). Swimmers trained with a snorkel during one week to get used with the equipment, also using a nose clip and open turns to familiarise with testing conditions. The experimental protocol was composed of a 200 m front crawl effort at maximal speed (T200). Before T200, swimmers performed a 400 m low-intensity front crawl warm-up, 200 m with the same snorkel used for training plus 200 m with a low hydrodynamic snorkel (Aquatrainer, Cosmed, Italy; Baldari et al., 2013) and a nose clip used for gas collection. Participants were instructed to start in-water and not perform lateral breath movements, open turns or underwater streamline after the wall push. During the T200, gas exchange data was collected and a digital video was recorded in the swimmers' sagittal plane (described below), with their total time assessed using a manual chronometer (Casio HS-30W). All experimental sessions were performed in a 25 m heated indoor pool, with $\sim 29^{\circ}\text{C}$ water temperature, between 15:00 and 19:00. During the T200, HR was monitored with a chest strap (Garmin, 920XT, EUA), with the maximum HR (HRmax) defined as the highest value recorded during the test.

The expired VO_2 concentration was measured breath-by-breath using a telemetric portable gas analyser (K5 ergospirometer, Cosmed, Italy) connected to the swimmer by an appropriate snorkel (Aquatrainer, Cosmed, Italy; Ribeiro et al., 2015). The K5 was calibrated according to the manufacturer's instructions and suspended 2 m over the water with a steel cable, following the swimmer along the pool while minimising water disturbances created by the equipment. The T200 began after the respiratory exchange ratio stabilised around 0.8. After the test, noises were omitted from analysis to minimise breath disturbance and only VO_2 values within ± 4 standard deviations of the mean were included (Fernandes et al., 2012). VO_2 values were smoothed using a breath moving average and time average to produce a standard weighted response at 5 s intervals (Fernandes et al., 2012). $\text{VO}_{2\text{peak}}$ was the highest value attained during the T200 (Ribeiro et al., 2015).

Kinematics data collection was performed using 2D video recording, with a video camera (SONYVHD3-CX260, Japan), at a 60 Hz sampling rate, positioned 2 m above the water surface and 5 m from the perpendicular line of swimmers' movement. Before each test, a 4.5 m long calibration frame was positioned at the sagittal plane in the middle of the pool, being that image used for digitalisation. After the experiments, videos were downloaded and digitalised using Kinovea open source software (www.kinovea.org) to obtain SL and SR values. Frames and pixels of swimmers left hand entry were recorded for at least two

cycles inside the calibrated area. SL and SR were calculated for each 50 m lap and v was obtained by multiplying SR and SL (calculated for each T200 50 m lap). Average SL and v values were used to obtain SI according to the equation $SI = v * SL$ (Costill et al., 1985).

STATISTICAL ANALYSIS

Data normality was checked using the *Shapiro-Wilk* test, with descriptive statistics being presented as mean $\pm$ SD and 95% confidence interval for all measured variables. One-way analysis of variance (ANOVA) was applied for group comparisons and two-way ANOVA was used for comparisons between groups and T200 laps (50, 100, 150 and 200 m). The effect size was obtained from η squared and classified as small, medium or large (η^2 0.01, 0.06 and 0.14, respectively; Cohen, 1988). Correlations between variables and T200 performance were tested with Pearson's correlation coefficient. The IBM SPSS statistical package was used for analysis (statistical significance was set at 5%) and, to better discuss the results, percentage differences between groups were calculated.

RESULTS

T200 performance decreased with ageing: 159.7 ± 11.7 , 181.8 ± 20.8 and 211.0 ± 23.0 s for G1, G2 and G3, respectively ($p < .001$; $\eta^2 = 0.61$). Although there were no differences between groups regarding anthropometric values, age partly explained height, arm span and body fat variances. Regarding swimming performance, FINA points were higher for the youngest group compared to oldest one, indicating that the former performed better in competition. Table 2 displays the physiologic and biomechanical data obtained during the T200, without being detected any differences for baseline HR and VO_2 among all age groups. However, HRmax and VO_{2peak} were smaller in G3 compared with the other groups, with ageing explaining 30 and 59% of the HRmax and VO_{2peak} variance (respectively). Complementarily, lower SL and SR values were detected for G3 comparing to G1, with v decreasing with increasing age. SI exhibited higher values for G1 comparing to G2 and G3.

TABLE 2. Mean $\pm$ SD and confidence interval values regarding master swimmers physiologic and biomechanics variables.

	Group 1 (n= 8) 33.9 $\pm$ 1.7 years	Group 2 (n = 8) 44.7 $\pm$ 1.9 years	Group 3 (n = 7) 59.4 $\pm$ 8.7 years	F(df); p; η^2
HR baseline (bpm)	767 $\pm$ 7]70 – 84[	78 $\pm$ 12]63 – 93[	73 $\pm$ 7]67 – 79[	F(2.19) = 1.22; p = .32; η^2 = .11
HRmax (bpm)	165 ^a $\pm$ 9]155 – 175[	156 ^{a,b} $\pm$ 13]140 – 172[	150 ^b $\pm$ 14]137 – 162[	F(2.19) = 4.14; p = .032; η^2 = .30
VO₂ baseline (mL.kg.min⁻¹)	6.7 $\pm$ 0.5]6.1 – 7.3[	5.8 $\pm$ 0.7]4.9 – 6.8[	6.5 $\pm$ 1.0]5.5 – 7.4[	F(2.18) = 0.92; p = .42; η^2 = .10
VO_{2peak} (mL.kg.min⁻¹)	52.5 ^a $\pm$ 6.3]45.9 – 59.2[	47.3 ^a $\pm$ 4.4]41.7 – 52.9[	38.6 ^b $\pm$ 5.5]33.6 – 43.7[	F(2.18) = 13.44; p < .001; η^2 = .59
SL (m)	1.93 ^a $\pm$ 0.14]1.78 – 2.08[	1.70 ^{a,b} $\pm$ 0.20]1.45 – 1.96[	1.64 ^b $\pm$ 0.20]1.45 – 1.82[	F(2.20) = 6.19; p = .008; η^2 = 0.38
SR (cycle.min⁻¹)	36.6 ^a $\pm$ 3.6]33.0 – 40.2[	36.0 ^{a,b} $\pm$ 5.4]29.4 – 42.0[	33.0 ^b $\pm$ 10.8]31.8 – 33.6[	F(2.20) = 4.09; p = .033; η^2 = .29
v (m.s⁻¹)	1.16 ^a $\pm$ 0.76]1.08 – 1.25[	1.00 ^b $\pm$ 0.06]0.93 – 1.08[	0.89 ^c $\pm$ 0.08]0.82 – 0.97[	F(2.20) = 25.58; p < .001; η^2 = .71
SI (m².s⁻¹)	2.25 ^a $\pm$ 0.22]2.02 – 2.48[	1.71 ^b $\pm$ 0.20]1.45 – 1.96[	1.48 ^b $\pm$ 0.32]1.18 – 1.77[	F(2.20) = 17.17; p < .001; η^2 = .25

NOTE 1: HR = heart rate; HR baseline = HR at rest; HRmax = T200 maximum HR; VO₂baseline = VO₂ at rest. SL = distance covered by the swimmer's body at each stroke cycle; SR = stroke rate; v = swimming speed; SI = stroke index.
Note2: Different letters indicate groups difference, p < .05

Figure 1 shows the SL, SR and v behaviour along the T200 for each age group. Comparisons among groups did not reveal any significant differences, showing similar patterns along the 200 m laps. SL results were similar for the 50 and 100 m laps but both were longer than the SL for the 200 m lap (nevertheless the SR increased in the final lap). SR and v data suggest a U-shaped performance behaviour, with the values starting higher and tending to decrease before they increased again for the final lap. When all study participants were analysed as a single group, there were inverse correlations between swimming performance (T200 performance, in s) and SL ($r = -.72$; $p < .001$), SR ($r = -.58$; $p = .003$), SI ($r = -.89$; $p < .001$) and VO_{2peak} ($r = -.81$; $p < .001$).

FIGURE 1. SL (upper panel), SR (middle panel) and v (bottom panel) at each 50 m lap of T200. Note: a indicates difference for 100 m ($p < .05$); b indicates difference for 150 m ($p < .05$); c indicates difference for 200 m ($p < .05$).

DISCUSSION

The current study compared $\text{VO}_{2\text{peak}}$, HR, SR, SL SI and v of different age groups master swimmers during a maximal effort, and related physiological and kinematic variables with performance. Furthermore, anthropometric characteristics were analysed. The main results showed that: (a) younger master swimmers performed better compared to older ones; (b) anthropometrics were not different among age groups (but there was a large age effect); (c) ageing explained 30 and 59% of the HRmax and $\text{VO}_{2\text{peak}}$ data variance (respectively); (d) kinematic variables showed significant difference between the G1 and G3 groups (with a prominent effect of ageing); (v) biomechanical variables behaved similarly for all age groups during the T200; (vi) SL, SR, SI and $\text{VO}_{2\text{peak}}$ were strongly correlated with T200 performance.

Swimming performance is multifactorial, depending on specific anthropometric characteristics and body composition, energetic systems, and adequate technique to generate less drag and higher propulsive forces (Figueiredo et al., 2013; Lätt et al., 2010). As expected, performance decreased as age increased, with previous 200 m front crawl analysis indicating that performance decline starts at age 45, but metabolic power declines 1% per year between the ages of 40 and 70 (Zamparo, Gatta, & di Prampero, 2012).

Compared to elite swimmers, master swimmers perform worse in the T200 (under the same conditions as in this study): 141.3 ± 4.7 s (Figueiredo, Zamparo, Sousa, Vilas-Boas, & Fernandes, 2011) and 140.5 ± 22.4 s (Reis et al., 2012) versus 159.7 ± 11.7 s for G1. Besides being younger (17.1 ± 2.3 and 21.6 ± 2.4 years for Reis et al. [2012] and Figueiredo et al. [2011], respectively), elite swimmers train more (Shaw, Boyd, Burke, & Koivisto, 2014), leading to more relevant energy system adaptations and technique improvement (Aspenes & Karlsen, 2012). Since, there is a lack of studies that examine master swimmers using the same protocol conditions, FINA points was used for comparison. Similar to T200 performance, younger master swimmers (29.75 ± 3.8 years) had higher points (491.8 ± 79.7 points) compared to G1 (Mejias et al., 2014). However, master swimmers in the same age group as G1 had similar FINA points: 315.0 ± 128.6 points (Ferreira, 2015) versus 368.8 ± 72.6 points.

Despite performance differences, the anthropometric characteristics were similar among the studied groups, with a large effect caused by ageing. Nasirzade et al. (2015) observed robust correlations between 200 m front crawl race performance and body height or arm span. The correlation between linear anthropometric measurements and swimming performance can be explained by the inverse relationship between wave drag and height (Toussaint et al., 2002). This relationship between performance and anthropometry was also demonstrated in a study with master swimmers over 50 to 800 m distances but, when the group was separated by sex, there were no correlations between performance and height or arm span, indicating the influence of other physiological and/or biomechanical variables on performance (Zampagni et al., 2008).

Age also had a considerable effect on body composition, specifically body fat. No relationship between body fat and lean mass with 100 yards swimming performance was observed (Siders, Lukaski, & Bolonchuk, 1993) but, more recently, it was verified that an increase in lean mass and muscle cross-sectional area and decrease in body fat over a season significantly improves performance (Roelofs, Smith-Ryan, Trexler, & Hirsch, 2017). Thus, body composition changes could be related to better performance but not exclusively since physiological and kinematic variables also change. Although our master swimmers body fat percentages were lower compared to the overall population (Imboden et al., 2017), values are 36-56% higher than top-level swimmers' values (Colyer et al., 2016; Roelofs et al., 2017; Santos et al., 2014), indicating that master swimmers have lower fat mass and lean mass ratio compared to top-level swimmers, which can negatively influence performance.

Ageing also directly affects muscles fibres (even if the body fat remains the same) and leads to a decrease in number and size of type II muscle fibres (Dube et al., 2016). Since this fibres type are recruited in high-intensity exercises or highly fatigable activities and have more developed anaerobic pathways, its decrease leads to muscle strength loss during ageing (Tieland, Trouwborst, & Clark, 2018). This phenomenon occurs even in master athletes engaged in systematic strength training, where the explosive strength and power falls more drastically than maximum strength (Ojanen, Rauhala, & Häkkinen, 2007). This could be a justification for the performance changes observed in the current study, since the 200 m front crawl effort has an ~35% anaerobic contribution, from which ~22% is alactic (Figueiredo et al., 2011). By analysing the T200 laps, Figueiredo et al. (2011) have found higher anaerobic contributions on the first 50 m, with the alactic pathway declining progressively during the test and the aerobic contribution increasing at the 100 m and remaining stable until the end of the swim. These results highlight the importance of the anaerobic system to 200 m swimming performance.

$\text{VO}_{2\text{max}}$ is one variable used for physiologic capacity evaluation, with the aerobic capacity (the maintenance of a high VO_2 level for a long period of time) being one of the main determinants for swimming performance (Zacca & Castro, 2012). Since it is not possible to identify VO_2 plateau values in the T200 (Sousa et al., 2011), aerobic capacity can be evaluated using the $\text{VO}_{2\text{peak}}$ (Ribeiro et al., 2015). When compared with top-level swimmers, master swimmers have lower $\text{VO}_{2\text{peak}}$: from 59.1–57.5 mL.kg.min⁻¹ (Castro & Mota, 2010) using the backward extrapolation method until values around 64 to 69 mL.kg.min⁻¹ using a direct method (Reis et al., 2012; Sousa et al., 2011). Knowing that aerobic capacity decline is inevitable with ageing, even for individuals engaged in endurance training (Tanaka & Seals, 2003), this underscores why G3 had the lowest $\text{VO}_{2\text{peak}}$ values. During an incremental test, a major contribution from the aerobic system and higher exercise economy (greater fat oxidation in relation to carbohydrates) is associated with lower $\text{VO}_{2\text{peak}}$ in master compared to younger endurance athletes (Dube et al., 2016). Therefore, the

lower $\text{VO}_{2\text{peak}}$ in the G3 is due in part to metabolic modifications that lead older athletes to be more economical during exercise.

Ageing-related HRmax decrease is one factor that influences maximum aerobic capacity, since these variables are related (Fick equation; Reaburn & Dascombe, 2008). Although HRmax decreased with age, this data should be interpreted with caution, since the aquatic environment directly influences HR that can change according to body position, immersion depth, water temperature, resting HR, decrease in hydrostatic weight and training level (Graef & Kruel, 2006; Holmér, 1992).

Figueiredo et al. (2011) found that, although biomechanical contribution to performance decreases in relation to energetics and muscular aspects along the 200 m test, its contribution to the mean velocity was still high: 58.1%, with SR and SL being responsible for 33.7% of the mean velocity. This finding indicates that biomechanical variables are important for performance. Our test conditions, which did not include the block exit, flip turn and underwater streamline after the wall push, directly affected speed, but SL and SR do not change (Barbosa et al., 2010) allowing comparisons with 200 m competitive events. The mean SR and SL values were lower than those reported for top-level swimmers in 200 m freestyle event, where SR varied from 38.3 to 46.8 cycles.min⁻¹ and SL from 2.1 to 2.5 m (Arellano, Brown, Cappaert, & Nelson, 1994; Castro & Mota, 2008; Figueiredo et al., 2011; Huot-Marchand, Nesi, Sidney, Alberty, & Pelayo, 2005; Simbaña-Escobar, Hellard, Pyne, & Seifert, 2018).

Several master swimming related studies evaluated biomechanical variables over different distances and times: 50 m (Espada et al., 2016; Favaro & Lima, 2005), 4 min moderate intensity (Zamparo, Dall'ora, et al., 2012), four-to-five different intensities (Zamparo, 2006), an incremental test of 7 x 200m (Mejias et al., 2014), 200 m with only upper limbs propulsion (Zamparo, Turri, Silveira, & Poli, 2014) and 200 m front crawl (Gatta, Benelli, & Ditroilo, 2006). Since intensity, distance and lower limbs action influence SR and SL (Silveira, Castro, Figueiredo, Vilas-Boas, & Zamparo, 2017), it is only possible to compare our results with the 200 m front crawl test fully analysed, not by its partials. SL relates to the swimmer's technical quality (Zamparo, Carrara, & Cesari, 2017) and fatigue tolerance, since swimmers who maintain high SL values at the end of the 200 m race perform better (Craig, Skehan, Pawelczyk, & Boomer, 1985). We observed that our G3 SL was ~24 and 16% shorter compared to the 55-59 and 60-64 year-old groups from Gatta et al. (2006) and, regarding SR the G3 was ~17% lower. To reach and sustain high-speed swimming, appropriate SR values are required. Such SR values are achieved and maintained at the expense of well-developed aerobic and anaerobic capacities (Termin & Pendergast, 2000).

When analysing master swimmers of three expert levels, one study found that at high speeds the swimmers with higher skill levels have better technique and consequently better SR and SL (Zamparo et al., 2017). Additionally, as the technical level declined among the three groups of the current study, the same effect occurred for swimming performance.

However, despite the different swimming performance level of master swimmers, results from official events indicate that SL and SR fall with ageing, with SR decline being more evident (Gatta et al., 2006). The SL decrease with age is associated with a propulsive efficiency decline that ultimately reduces swim speed (Zamparo, Dall'ora et al., 2012). The SL decrease with a compensatory increase of the SR in relation to the v during the 200 m test is well established (Chollete, Pelayo, Torny, & Sidney, 1996) since muscle fatigue increases with a concomitant decrease in alactic and increase in the lactic anaerobic contribution along the effort and, consequently, SL and propulsive efficiency decrease and SR increases in an attempt to maintain high speed (Figueiredo et al., 2011, 2013).

There are several swimming race strategies, depending on distance and swimming technique (McGibbon, Pyne, Shephard, & Thompson, 2018). Analysis of international 200 m events revealed that swimmers select an “even pace” characterised by a high speed during the first lap, followed by two slower intermediate partials and a finish at the same speed or just above the intermediate ones (Castro, Diefenthaler, Colpes, Silveira, & Franken, 2017; Robertson, Pyne, Hopkins, & Anson, 2009), which correlates most with performance for all 200 m events (McGibbon et al., 2018). The results obtained in a T200 with elite swimmers (under the same conditions as in the current study; Figueiredo et al., 2011) evidenced an even pace strategy, as expected. When analysing v , we have observed that the strategy adopted by master swimmers is to start the first 50 m lap fast, swim lower 100 m and 150 m laps and finish the final lap at the same speed as the first one, producing a parabolic or U-shaped trend, a test pattern similar to the 400 m freestyle event (McGibbon et al., 2018).

SI is a good indirect indicator of swimming economy since it describes the swimmer's ability to move at a given speed with the fewest cycles possible (Costill et al., 1985). G1 swimmers had SI 24 and 13.4% higher compared to G2 and G3 (respectively). Zamparo, Dall'ora et al. (2012) found differences between mean swimming speed over age groups (30 to 80 years), and swimmers older than 40 years have a higher energy cost than younger ones. Furthermore, when energy cost values were compared with younger elite swimmers for the same speed, it increased 0.75% per year. When analysing energy requirement and available energy during 200 m races by mathematical methods, Zamparo, Gatta et al. (2012) found both a decrease in available aerobic and anaerobic energy and an increase in energy cost. In the current study, there was a negative correlation between swimming performance and SR, SL and SI in accordance with previous observations (Arellano et al., 1994; Figueiredo et al., 2013; Nasirzade et al., 2015). These findings suggest that master swimmer training should be developed beyond metabolic training, focusing also in technical quality, a strategy that would increase propulsive efficiency and decrease the cost of locomotion (Zamparo, Gatta et al., 2012).

Although swimmers were familiarised with the use of the snorkel, it is possible that the decreased speed during the last T200 lap was not compensated by increased confidence to breath in the snorkel during the test, which could cause the swimmers to perform previous laps at a lower intensity than they would under competitive conditions. This lower intensity may have contributed to the large variation in HRmax results, and might be considered as a study limitation. Furthermore, master category is very heterogeneous in terms of swimming experience and current training status, variables that were not included in the current analysis, and that should be considered also in future studies as performance determinants. In conclusion, T200 performance declines as age increases and $\text{VO}_{2\text{peak}}$ and kinematic were the elected performance predictive variables. However, despite the great influence of the physiological variables on energy system capacity, swimming kinematics is central in the production of propulsive forces and drag decrease. Thus, master swimmers should exercise beyond total metabolic power, including relevant technical development training.

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