

Factors influencing master swimming performance: a multivariate analysis of the 200 m front crawl

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Abstract

Master swimming is experiencing a notable increase in participation rates and performance standards. Various factors influence swimming performance, including biomechanical, physiological, and anthropometric elements. This study explored the intricate relationship between these factors and performance in the 200 m front crawl all-out test (T200) among master swimmers. Eighteen male master swimmers (age: 46.3 ± 14.0 years; body mass: 78.0 ± 7.2 kg; height: 1.77 ± 0.06 m) underwent evaluation encompassing anthropometry, body composition, T200 performance, physiological, and biomechanical variables. Physiological and biomechanical data were collected during the T200. Statistical analyses, including correlation and stepwise regression, were conducted at a significance level of $\alpha < 0.05$. Performance in the T200 (time: 185.8 ± 28.9 s) exhibited significant correlations ($p < 0.05$) with peak oxygen consumption ($\text{VO}_{2\text{peak}} = 43.9 \pm 7.3 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) ($r = -0.81$), maximal heart rate ($\text{HR}_{\text{max}} = 156.5 \pm 13.1$) ($r = -0.58$), stroke length ($\text{SL} = 1.75 \pm 0.21$ m) ($r = -0.72$), stroke rate ($\text{SR} = 34.8 \pm 3.6 \text{ cycle}\cdot\text{min}^{-1}$) ($r = -0.58$), and arm stroke efficiency ($\eta\text{P} = 31.9 \pm 3.8\%$) ($r = -0.72$). Multicollinearity analysis ($p < 0.05$) excluded HR_{max} (which correlated with $\text{VO}_{2\text{peak}}$, $r = 0.65$) and ηP (which correlated with SL , $r = 0.99$). The resulting regression model included SR , SL , and $\text{VO}_{2\text{peak}}$, explaining 48.0%, 48.2%, and 3.7% of T200 performance variance, respectively. Notably, the biomechanical components— SL and SR (kinematics)—are primary determinants of T200 performance, with $\text{VO}_{2\text{peak}}$ making a relatively small contribution. Consequently, master swimming training should prioritize technical development to enhance efficiency.

Keywords: active aging, sport assessment, oxygen consumption, kinematics

Introduction

The master swimming population comprises individuals aged 25 years and older¹, exhibiting a diverse range of swimming experience and performance levels². Moreover, participants in master events actively engage in structured and consistent training aimed at enhancing athletic performance³, thereby highlighting the necessity to understand various factors influencing swimming performance in this specific population. The assessment of swimming performance is primarily based on the time taken to traverse a specific distance, ultimately determining swimming velocity (v). Such displacement in the aquatic environment is contingent upon the resultant force generated through propulsion, which stems from the interplay between propulsive and drag forces⁴. Propulsive force is influenced by an individual's physiological, morphological, and technical attributes, while drag force predominantly depends on technique⁵. However, drag force is also influenced by the swimmer's physical attributes [such as peak oxygen consumption ($\text{VO}_{2\text{peak}}$) and muscle strength] and anthropometric characteristics [including stature, arm span, and body fat (%)]⁴.

Regarding swimming energetics, oxygen uptake (VO_2) is a crucial metric for describing physiological attributes⁶ and is a strong predictor of competitive level⁷. Previous research has identified a significant inverse relationship between $\text{VO}_{2\text{peak}}$ and 200 m front crawl performance in young adults⁸; however, investigations among master group swimmers remain scarce⁹. Conversely, biomechanical factors, which influence drag and/or propulsive force generation, exert a more pronounced effect on performance than the capacity for energy production and release¹⁰.

Among these biomechanical parameters, the analysis of stroke length (SL), stroke rate (SR), trunk inclination (TI), and kick rate (KR) allows the evaluation of swimming kinematics and technique¹⁰⁻¹². Master swimmers typically exhibit lower SL and SR than their higher-level counterparts¹³, directly impacting v because clean v is the product of SL and SR . Moreover, SL and SR also affect arm stroke efficiency (ηP) (i.e., the percentage of force applied by the swimmer in the water that effectively generates propulsion), which tends to be

lower in master swimmers¹⁴. TI directly influences drag and, consequently, the energy expenditure associated with swimming¹¹. A higher TI leads to a larger body area being projected into the water, thereby increasing drag¹¹. Additionally, swimming energy expenditure rises in response to an increase in KR. Thus, a low KR is recommended for events where power is not a primary requirement, and leg kicks are used solely for stabilization and to increase upper limb propulsion¹⁴.

The correlation between anthropometric linear measures and swimming performance can be explained by the inverse relationship between wave drag and swimmer height (where wave drag decreases as height increases)¹⁵. While improvements in body composition, namely the reduction in body fat and increase in muscle tissue resulting from training, appear to enhance performance¹⁶, it is noteworthy that a higher body density owing to lower body fat can adversely affect buoyancy and increase swimming energy expenditure¹⁷.

Given the increasing population of master swimmers who undergo systematic training to enhance performance in the multifaceted sport of swimming, it becomes imperative to ascertain the relationships among physiological, biomechanical, and anthropometric parameters with swimming performance to optimize training protocols. Such understanding can significantly improve the training regimen and the performance of swimmers in the master age category. Although factors influencing swimming performance have been explored in young individuals or adults^{5,8}, few studies have been conducted with swimmers in the masters age category⁹.

Thus, the primary objective of this study is to examine the relationship between physiological, biomechanical, and anthropometric parameters and swimming performance in a 200 m all-out front crawl test (T200) among master swimmers. We hypothesize that energetics, represented by $\text{VO}_{2\text{peak}}$, and biomechanical parameters related to propulsion and drag, specifically ηP and TI, will substantially influence performance in the 200 m front crawl. The findings of this study provide valuable insights for swimming coaches in refining their training methodologies.

Materials and methods

Eighteen male master swimmers volunteered to participate in the study (age 46.3 ± 14.0 years; *Fédération Internationale de Natation* (FINA) points 269.3 ± 135.4 ; and years of experience in training/competition 13.2 ± 2.5). Participants were instructed not to modify their lifestyle, including sleep and diet. Inclusion criteria comprised: (i) absence of musculoskeletal injury or discomfort during the study period; (ii) absence of cardiometabolic disease; (iii) not taking supplements or drugs; and (iv) regular training over the past two years (at least three swimming sessions per week, covering a minimum of 2,000 m per day)¹⁸, with participation in master regional and national competitions within the last year.

Exclusion criteria encompassed individuals who had not trained for more than four weeks before the study or had experienced injuries or illnesses during the study period. Before enrollment, participants were provided with detailed information regarding the study's risks and benefits and gave informed written consent. The study adhered to the principles outlined in the Declaration of Helsinki, following the update of Fortaleza 2013 (World Medical Association 2013), and received approval from the local ethics committee (approval number 67847417.0.0000.5347). All procedures were conducted in accordance with the Declaration of Helsinki (1964).

Participants completed questionnaires and reported their best competition results (in seconds) from the previous year, which were then converted into FINA points performance data (<http://www.fina.org/content/fina-points>). All swimmers were tested during the competitive calendar and were instructed to abstain from moderate to intense exercise (24 h before the test), alcohol consumption (72 h prior), or intake of caffeine or calcium-based medications (24 h prior) without previous communication with the research team. The assessment protocol comprised anthropometric evaluation and the T200.

During the T200, expired gas exchange data were collected, and digital images were captured in the swimmer's sagittal plane. All experimental sessions were performed in a 25 m heated indoor pool under controlled environmental conditions (approximately 28°C water temperature, between 15:00–19:00 h). In the familiarization phase, concurrent with regular weekly swimming training (three times per week covering a minimum of 2,000 m), swimmers underwent one week of training with open turns and practiced with a snorkel and nose clip to get used to the equipment and techniques²⁰. Before T200, swimmers completed a 400 m low-intensity front crawl warm-up, followed by 200 m with the same snorkel used for training, and 200 m with a low hydrodynamic snorkel for respiratory gas collection (Aquatrain, Cosmed, Italy), along with the nose clip²⁰. Total time during the T200 was recorded using a manual chronometer by an experienced swimming coach and utilized as the performance parameter (s) (Casio HS-30W, Casio, Tokyo, Japan).

Anthropometric measurements were conducted in accordance with the International Society for the Advancement of Kinanthropometry (ISAK) protocol²¹. Body mass (kg) (balance G-Tech Glass 200®, 150 kg capacity, and 0.1 kg resolution, Brazil), height (cm) (portable stadiometer Cescor®, 3 m capacity, and 0.1 cm resolution, Brazil), upper arm span (cm) (anthropometric tape 3M, 2 m capacity, and 0.1 cm resolution, Brazil), and fat mass (%) (Dual-energy X-ray absorptiometry; Hologic Discovery W, EUA) were measured by an experienced researcher

following standard protocols.

T200 data collection and analysis

T200

Participants performed the tests using the front-crawl technique, receiving encouragement during the T200 to exert maximum effort. To mitigate the potential effects of block starts on swimming speed and owing to the utilization of a snorkel, swimmers initiated the test in the water and executed open turns²⁰. During the T200, heart rate (HR) was continuously monitored using a chest strap (Garmin, 920XT, EUA), with maximum HR (HR_{max}) defined as the highest recorded value during the test. Expired VO_2 concentration was measured breath-by-breath employing a telemetric portable gas analyzer (K5 Ergospirometer, Cosmed, Italy), connected to the swimmer via an appropriate snorkel (Aquatrainer, Cosmed, Italy)²². The gas analyzer was calibrated according to the manufacturer's instructions. It was suspended 2 m above the water surface using a steel cable, tracking the swimmer along the pool while minimizing water disturbances caused by the equipment²³. The T200 began after stabilizing the respiratory exchange ratio at approximately 0.8 when the swimmers remained at rest²³.

Data processing was performed after the test using the VO_2 FITTING (free and open-source software)²⁴. Only VO_2 values falling within ± 4 standard deviations of the mean were incorporated to reduce breath disturbance and noise²⁵, with VO_2 values smoothed via a breath moving average and time average to yield a standard weighted response at 5-s intervals²⁶. VO_{2peak} ($ml \cdot kg^{-1} \cdot min^{-1}$) was defined as the highest value attained during the T200²².

Kinematics data were collected through video recording at a 60 Hz sampling rate in 2D, utilizing two video cameras (SONYVHD3-CX260, Japan). One camera was positioned 2 m above the water surface and the other 50 cm beneath the water surface, both located 5 m from the perpendicular line of swimmers' movement. Before each test, a 4.5 m long calibration frame was positioned in the sagittal plane at the pool's midpoint, with the resulting image utilized for transforming pixels to meters. Data processing was performed using the Kinovea open-source software (www.kinovea.org) to obtain SL, SR, TI, and KR. For SL and SR data acquisition, frames and pixels of the swimmer's left-hand entry were recorded for at least two consecutive cycles within the calibrated area. SL (m) and SR (Hz) were calculated for each 50 m lap; v was then determined by multiplying SR and SL. The SR was then multiplied by 60 to obtain data in $cycles \cdot min^{-1}$. For each stroke cycle, leg kicks were counted to acquire KR ($kicks \cdot cycle^{-1}$). ηP (%) was calculated using the simplified model²⁷ described in Equation 1:

$$\eta P = \left(\frac{v \cdot 0.9}{(2 \cdot \pi \cdot SR + 0.52)} \right) * 2/\pi * 100$$

where ηP is the arm stroke efficiency, v the mean swimming velocity, π is the mathematical constant approximately equal to 3.1416, SR is the stroke rate, and 0.52 is a constant representing the linear distance between the shoulder center and the hand center during the in-sweep phase (when the hand is positioned beneath the shoulder)²⁸. The TI was quantified by measuring the horizontal angle between the elbow and hip during one stroke cycle for each 50 m segment, specifically during the in-sweep phase, where trunk rotational movements have minimal influence²⁹. Figure 1 shows the setup employed for data collection during the T200.

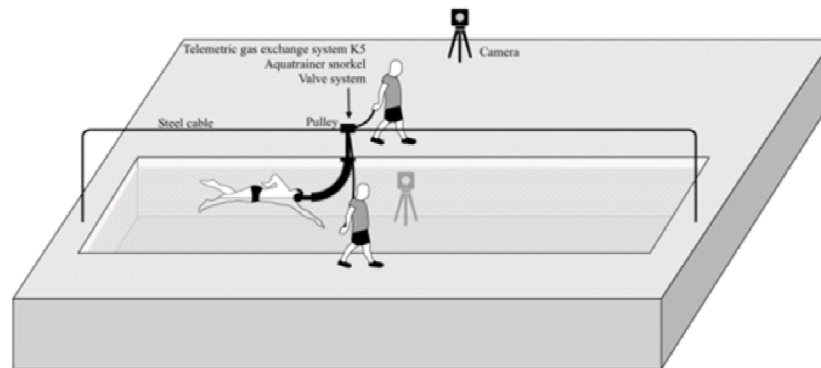


Figure 1.— Physiological and kinematics data collection set-up over the 200 m front crawl all-out test.

Statistical Analysis

Normal data distribution was assessed using the Shapiro–Wilk test. Data are presented as mean $\pm$ SD and 95% confidence interval for the mean for all measured variables. Multiple linear regression analysis, utilizing the "Enter" method, was employed to identify the most influential variables and their relative contributions to performance in the T200. First, Pearson's correlation coefficient was utilized to (i) identify potential predictor variables statistically correlated with T200 performance and (ii) detect multicollinearity among independent variables correlated with performance. When two independent variables exhibited a statistical correlation ($r \geq 0.7$ or -0.7) with each other and correlated with performance, the variable with the

highest correlation coefficient with performance was retained in the regression model. The objective of the regression analysis was not to predict performance but to ascertain the importance of variables to T200 performance³⁰. The Durbin–Watson test (DW) was conducted to verify the independence of residuals not explained by the generated regression model, with values ideally falling between 1.5 and 2.5. Standardized β coefficients were converted to percentages ($\beta_{\text{standardized}} \times 100 = 100\%$). Statistical significance was set at 5%. All analyses were performed using IBM SPSS version 23.

Results

Table 1 presents baseline data obtained from the participants, including mean values, standard deviations (SD), and confidence intervals for the mean.

Table 1. — Anthropometric, body composition, performance, physiological and biomechanical data from master swimmers.

n = 18	Mean	SD	Mean confidence limits (95%)
Body mass (kg)	78.0	± 7.2	[74.4 to 81.6]
Height (m)	1.77	± 0.06	[174.5 to 181.0]
Arm spam (m)	1.82	± 0.07	[178.8 to 185.8]
Body fat (%)	24.3	± 4.5	[21.8 to 26.4]
T200 (s)	185.8	± 28.9	[171.4 to 200.2]
VO _{2peak} (ml·kg·min ⁻¹)	43.9	± 7.3	[40.3 to 47.6]
HR _{max} (bpm)	156.5	± 13.1	[150.0 to 163.0]
SL (m)	1.75	± 0.21	[1.64 to 1.86]
SR (cycle·min ⁻¹)	34.8	± 3.6	[0.55 to 0.61]
KR (kick·cycle ⁻¹)	5.52	± 0.81	[5.12 to 5.93]
ηP (%)	31.9	± 3.8	[30.0 to 33.8]
TI (°)	9.7	± 2.4	[8.5 to 10.9]

Note: HR_{max} = maximum heart rate; SL=stroke length; SR=stroke rate; KR=kick rate; ηP = arm stroke efficiency; TI= trunk incline

Performance in the T200 exhibited statistically significant correlations ($p < 0.05$) with: VO_{2peak} ($r = -0.81$), HR_{max} ($r = -0.58$), SL ($r = -0.72$), SR ($r = -0.58$), and ηP ($r = -0.72$). Conversely, multicollinearity analysis eliminated the following variables: HR_{max} (which correlated with VO_{2peak}, $r = 0.65$) and ηP (which correlated with SL, $r = 0.99$). Thus, the regression model was constructed with VO_{2peak}, SL, and SR. The regression equation was significant ($F_{1, 14} = 67.2$; $p < 0.001$; DW = 2.41) with an adjusted R² of 0.93 (Equation 2):

$$T200 = (-358.5 * SR) + (-101.0 * SL) + (-0.22 * VO_{2peak}) + 528.3$$

The β values for predictor variables (SR, SL, and VO_{2peak}) were, respectively, -0.755, -0.759, and -0.058. Consequently, in relative terms, it can be concluded that SR, SL, and VO_{2peak} contribute 48.0%, 48.2%, and 3.7%, respectively, to performance, respectively (Figure 2).

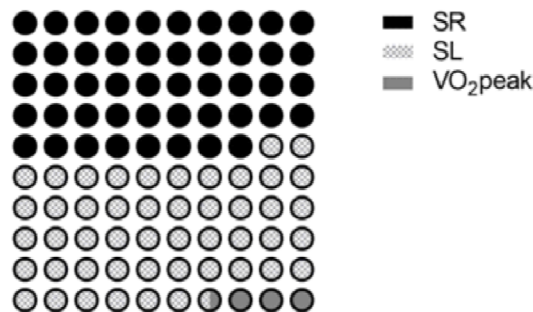


Figure 2. — Illustration of the percentage share of stroke rate (SR), stroke length (SL), and peak oxygen consumption (VO_{2peak}) determinations for 200 m front crawl all-out test (T200) performance.

Discussion

This study examined the relationship between various physiological, biomechanical, and anthropometric factors and swimming performance in the T200 among master swimmers. Our results show that certain kinematic variables (SL and SR) play a more significant role in T200 performance ($\approx 96\%$) than energetic factors like VO_{2peak} ($\approx 4\%$). Interestingly, anthropometric factors did not significantly impact performance. Thus, the initial hypothesis positing that energetic factors represented by VO_{2peak}, along with biomechanical parameters

related to propulsion and drag, such as ηP and TI, would strongly influence 200-meter freestyle performance was partially confirmed. Specifically, while VO_{2peak} showed a minor influence on performance, neither ηP nor TI were included in the regression model.

This result was consistent with prior research on highly skilled swimmers, indicating that technical parameters are the predominant performance determinants, overriding other physiological measures (e.g., VO_{2peak}), regardless of the specific swimming distances involved³⁰⁻³³. Swimming speed depends on the interplay between SL and SR⁷. Lower SR and higher SL correlate with improved performance in swimming⁴. A previous study³⁴ analyzed master swimmers from three expert levels. It was discovered that an increase in swimming speed corresponds to a higher skill level in the swimmer, indicative of superior technique and a more harmonious relationship between SR and SL. Similar results were obtained in the study of younger master swimmers, who exhibited increased SL and SR and achieved greater velocity (because clean swimming velocity = $SL \times SR$) than the older age group during a T200 test⁸. In elite swimmers, the contribution of SR and SL to mean velocity remains significant throughout the T200 test, albeit diminishing as the test progresses³⁵. At a given swimming velocity, swimmers of higher skill levels tend to have lower SR and longer SL, requiring less internal power for movement. This increased efficiency results in reduced energy expenditure during swimming³⁶.

Aerobic power is the capacity to utilize the aerobic energy system during physical activity efficiently. Swimmers capable of maintaining a high VO_2 level over extended durations at a consistent speed exhibit greater energy efficiency and potentially achieve superior performance levels²⁷. Research involving young and elite swimmers demonstrates that performance is strongly linked to the energetic profile, particularly VO_{2peak} . The swimmer's technical proficiency influences this profile⁷. Because swimming is a highly technical sport, motor patterns significantly impact energy expenditure³⁷. Consequently, athletes with lower technical proficiency may display differences in energy contributions, influenced by diminished propulsive force and/or increased drag.

While the energetic contribution of VO_{2peak} to performance may be relatively small (approximately 4%), its impact remains significant in swimming, where even fractions of a second are critical. Maximal oxygen consumption is a crucial energetic metric used to assess swimmers' maximal aerobic performance⁶. It correlates with 200 m swimming performance across different groups, including young adult, elite, and sub-elite swimmers^{35, 38}. In the absence of maximum oxygen uptake (VO_{2max}), VO_{2peak} can be a useful indicator of aerobic capacity^{22, 38}. A well-developed aerobic system can significantly enhance performance because the 200 m race relies heavily on the aerobic system (~66%)³⁵. In this study, multicollinearity testing excluded HR_{max} owing to its correlation with VO_{2peak} . A more efficient cardiovascular system response is associated with improved oxygen delivery (e.g., Fick equation)³⁹.

Despite arm stroke efficiency being excluded by the multicollinear test, it showed a negative correlation with T200 performance. The ηP represents the efficiency of the work used to propel the body forward, influenced by anthropometric characteristics and technical skills⁴⁰. Less skilled swimmers tend to waste more power moving masses of water rather than overcoming drag and generating propulsion⁴¹. A previous study⁴² analyzing the ηP in master swimmers of varying ages found that both ηP and SL decreased steadily with increasing age. In the elder male swimmer group (54 years), the values for ηP were lower, and for SL, similar to those observed in children. These findings suggest that ηP is more dependent on SL than on the shoulder-to-hand distance. These results underscore the importance of developing master swimming techniques to enhance propulsion efficiency and reduce energy expenditure during aquatic locomotion.

The KR and TI did not correlate with T200 performance. KR is directly linked to swimming energy expenditure because it rises in response to increases in KR¹². However, the lower limbs play crucial roles in trunk balance, buoyancy, and overall coordination, increasing SL¹². In faster events, a greater demand for leg kicking leads to increased energy expenditure⁷. In the 200 m front crawl, the KR becomes increasingly crucial to performance as fatigue sets in throughout the distance. Thus, propulsion from the lower limbs is essential in this event, in addition to overall body stabilization¹². A streamlined body position is a key factor influencing performance because it determines the projected frontal area, affecting drag forces. As swimming velocity decreases, the TI increases, leading to an increase in projected frontal area²⁷.

Performance in swimming was not influenced by anthropometric factors such as body mass, height, upper arm span, or body fat percentage, which contrasts with other sports where these variables are known to impact performance significantly³⁰. A thorough discussion on body composition in master swimmers can be found elsewhere². Master swimmers come from diverse backgrounds, and many begin swimming in adulthood⁴², resulting in a heterogeneous population. Therefore, it is expected that swimming efficiency, heavily reliant on technical skills, allows a master athlete with less favorable body composition or anthropometric characteristics but superior skill to outperform their counterparts. Swimming performance is influenced by multiple factors³³. While studies with master populations have typically examined performance-related aspects through bivariate analysis, incorporating biomechanical, energetic¹³, and dry land power variables⁴³, integrative analyses have primarily been conducted with higher-level swimmers^{30, 31, 33}. For instance, a previous study³⁰ analyzed determinants of performance in the 200 m front crawl among well-trained swimmers (age: 21.6 ± 2.4 years) and yielded similar findings to our study, with biomechanical parameters emerging as the primary contributors to

performance. The authors conducted a regression analysis to evaluate the impact of biomechanical, energetic, coordinative, and muscular factors on performance. The findings revealed that biomechanical factors contributed 58.1%, energetic factors contributed 11.2%, coordinative factors contributed 18.9%, and muscular factors contributed 11.8%. SL and SR collectively accounted for 33.7% of the mean velocity in the 200 m swim. The average velocity of master's swimmers in this study (≈ 1.07 m/s) differed significantly from the elite swimmers in another study (≈ 1.41 m/s)³⁰. These findings suggest that as swimmers reach higher skill levels, energetic variables may have a greater impact on 200 m test performance (11.8% vs. 3.68% in our study).

Master swimmers demonstrated comparable velocities to prepubertal and pubertal swimmers³¹ in their 400 m tests (0.99 ± 0.12 and 1.12 ± 0.13 m/s, respectively). Among these samples, stroke index, arm span, and $VO_{2\text{peak}}$ emerged as the primary determinants of swimming performance, with biomechanical factors exerting the greatest influence, accounting for 89.8%, followed by body composition (45.4%), and bioenergetic capacity (35.8%)³¹. This underscores the substantial impact of biomechanical variables on swimming performance while suggesting that the magnitude of energetic contributions diminishes with lower technical proficiency. However, even small improvements in each variable can produce systemic changes, thereby influencing the dependent variable, swimming performance. Thus, future research employing methodologies such as network analysis could offer deeper insights, particularly considering the limitations of regressions in handling variables with low correlations, thus enhancing our understanding of master swimming performance. The data suggest that for master athletes, technical skills, as evaluated by biomechanical parameters like SR and SL, should be integrated into a comprehensive training regimen alongside energetic capacities (both aerobic and anaerobic). This balanced approach can help develop a more efficient biomechanical pattern, which can significantly influence swimming performance.

Our study has several limitations. We did not measure blood lactate concentration, which could have provided valuable insights into the energetic contributions to T200 performance. Additionally, the absence of older master swimmers in our sample limits our understanding of the relationship between aging and sports participation. Future investigations should address these gaps and explore similar issues among female master swimmers, given their distinct morphological, biomechanical, and physiological characteristics. Furthermore, longitudinal studies examining swimming performance alongside aging and physiological and biomechanical changes among masters age category swimmers could yield valuable insights into the combined effects of aging and training on performance and overall quality of life.

Conclusions

Master swimmers dedicate themselves to systematic training programs aimed at enhancing performance. Swimming performance, measured by the time taken to cover a specific distance, is influenced by various factors. While significant correlations exist between performance in the T200 and variables such as $VO_{2\text{peak}}$, HRmax, SL, SR, and ηP , the biomechanical profile, particularly kinematics (SL and SR), predominantly determines T200 performance. As indicated by $VO_{2\text{peak}}$ data, energetic contributions play a smaller role. Consequently, these findings underscore the importance of focusing master swimmers' training efforts on improving technical skills, particularly in optimizing the relationship between SL and SR, which are closely linked to swimming technique.

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Conflict of interest

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Authors' contributions

Author CDZT, CDS, and FASC have given substantial contributions to the conception or the design of the manuscript, author CDZT and author FASC to acquisition, analysis, and interpretation of the data. All authors have participated to drafting the manuscript, author SBF revised it critically. All authors read and approved the final version of the manuscript.

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