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

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Abstract

Ferreira, MI, Barbosa, TM, Costa, MJ, Neiva, HP, and Marinho, DA. Energetics, biomechanics, and performance in masters' swimmers: a systematic review. *J Strength Cond Res* 30(7): 2069–2081, 2016—This study aimed to summarize evidence on masters' swimmers energetics, biomechanics, and performance gathered in selected studies. An expanded search was conducted on 6 databases, conference proceedings, and department files. Fifteen studies were selected for further analysis. A qualitative evaluation of the studies based on the Quality Index (QI) was performed by 2 independent reviewers. The studies were thereafter classified into 3 domains according to the reported data: performance (10 studies), energetics (4 studies), and biomechanics (6 studies). The selected 15 articles included in this review presented low QI scores (mean score, 10.47 points). The biomechanics domain obtained 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 (η_p) decreased with age. Swimming performance declined with age. The performance declines with age having male swimmers deliver better performances than female counterparts, although this difference tends to be narrow in long-distance events. One single longitudinal study is found in the literature reporting the changes in performance over time. The remaining studies are cross-sectional designs focusing on the energetics and biomechanics. Overall, biomechanics parameters, such as *SF*, *SL*, and η_p, tend to decrease with age. This review shows the lack of a solid body of knowledge (reflected in the amount and quality of the articles published) on the changes in biomechanics, energetics, and performance of master swimmers over time. The training programs for this age-group should aim to preserve the energetics as much as possible and, concurrently, improve the technique. Training sessions should feature a higher percentage of technical drills with the goal of enhancing the swim technique. Another goal should be the association of technique enhancement with aerobic and anaerobic sets, enabling the swimmer to improve the swimming efficiency.

Key Words swimming, aging, technique, physiology, swim stroke

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Introduction

Sport participation in masters' competitions has increased over the last couple of years (24,26) as reflected by the increasing number of athletes competing in the master world championships since the first championship held in Tokyo in 1986 (3,500 athletes) until the last held in 2015 in Kazan (6,318 athletes). In some way, this shows the interest that people have in healthy sport participation with the advancing age these days (26). Research comparing master athletes to sedentary subjects has found that many of the aging effects are the result of a sedentary lifestyle or disuse (8). Thus, research with master athletes can provide an excellent opportunity to investigate the effects of age in the metabolic/biomechanical determinants of performance (41). Doing so, it is possible to exclude physical inactivity as a potential confounding factor (1).

Swimming is probably the most or, at least, one of the most popular sports for master athletes. It imposes little strain, that is, it does not require carrying directly one's body weight, and thus is especially suitable for older subjects (31). The reasons beyond the participation of master athletes in competitions and/or in regular exercise are the enjoyment and the health benefits (35), as well as the will to enhance their performance (22). With aging population and the current trends toward increasing physical activity in adulthood, it is important to understand the relationship between age and physical performance and to identify the factors affecting it. Among the most important factors affecting performance in swimming are the energetics and biomechanics.

Both can be monitored during training sessions developed to improve both physiological and technical ability within and between seasons (6). Longitudinal studies are required to have such insight because cross-sectional designs are less informative about the cause-effect relationship in a long time frame (6). Another interesting topic of investigation is the gender gap in master swimmers considering that, compared with men, women have a greater loss of muscular function and capacity (27).

A few longitudinal studies in master swimmers can be found in the literature. These aimed to analyze the effect of age on performance. Yet, no studies are available reporting changes in energetics and biomechanics over a full season or even a longer time frame. Given the increasing number of participants in this age-group, as mentioned previously, 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 performed with masters' swimmers. Moreover, the information gathered here is expected to help coaches and swimmers to improve performance, assist coaches in their training prescription, and highlight areas for further research. For this, a systematic review was performed, summarizing evidences related to the effect of age on the energetics, biomechanics, and performance in masters' swimmers.

Methods

Experimental Approach to the Problem

This study aimed to summarize the findings reported in the literature on the effect of age on the energetics, biomechanics, and performance of master swimmers. A systematic review of the literature was carried out to gather such evidence. An extensive literature search was conducted to identify the articles published on this topic. Based on inclusion and exclusion criteria, a selected number of articles were kept for further analysis.

Search Strategy

An extensive literature search was conducted, from January 1, 1970, to March 31, 2014, to identify the studies in which biomechanics and energetics variables were reported for master swimmers. This was performed by running searches on databases (PubMed, ISI Web of Knowledge, Index Medicus, Medline, Scopus, and Sport Discus) using the key words "longitudinal," "masters' swimmers kinematics," "biomechanical," "energetics," "physiological," "performance," "swimming," and "training season," with multiple combinations and with no language restrictions. In addition, extensive searching and cross-referencing were performed by using the articles' metadata of studies already identified. Review articles (qualitative review, systematic review, and meta-analysis) were not considered. The energetics variables assessed were velocity at 4 $\text{mmol}\cdot\text{L}^{-1}$ of blood lactate concentration levels (v_4), maximal oxygen consumption ($\dot{V}O_2max$), 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 (η_p).

Inclusion and Exclusion Procedures

The included studies focused on cross-sectional and longitudinal interventions on energetics, biomechanics, and performance in master swimmers. "Masters" are defined as individuals who systematically train for, and compete in, organized forms of competitive sport specifically designed for adults and older adults (28). The minimum age of the subjects participating in the study was 25 years (inclusive). Studies based on other swimming topics, or using other chronological ages (e.g., children and elite swimmers) instead of master swimmers, were excluded.

Regarding the research question, studies were categorized into the following 3 main groups: (a) performance; (b) energetics; (c) biomechanics. The information extracted from the selected studies was based on research design, aim, subjects, procedures/outcomes, and findings.

Quality Assessment

For the quality assessment, the checklist reported by Downs and Black (9) was selected. This checklist was chosen because of the absence of a validated quality assessment tool suitable for sports performance. Two independent reviewers were briefed on how to do the interpretation of items featuring the checklist. Each reviewer did go through the selected studies checking if the items on the list were mentioned in those articles. For each item, a value was assigned and, at the end of the process, a final score was obtained. This final score indicates the quality assessment of the study, where the higher the value the better the quality. The checklist 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 was 32 points. The degree of agreement in the scoring procedure was based on the Kappa index (*K*), and thresholds were interpreted according to Landis and Koch's suggestion (21) with (a) $K \leq 0$ representing no agreement; (b) $0 < K \leq 0.19$ poor agreement; (c) $0.20 < K \leq 0.39$ fair agreement; (d) $0.40 < K \leq 0.59$ moderate agreement; (e) $0.60 < K \leq 0.79$ substantial agreement; and (f) $0.80 < K \leq 1.00$ almost perfect agreement.

Results

Our search identified 163 relevant articles of which 148 did not meet the inclusion criteria (Figure 1). The reasons for exclusion were studies being focused on other topics, such as body composition, anthropometric characteristics, skeletal muscle mass, and strength conducted among elite swimmers, and on participants of other chronological ages including young swimmers. Therefore, a total of 15 studies were considered for further analysis. From these, the earliest one was published in 1990 (29) and the most recent in 2014 (24).

The studies focusing on the energetics, biomechanics, and performance domains in masters' swimmers are recent, most

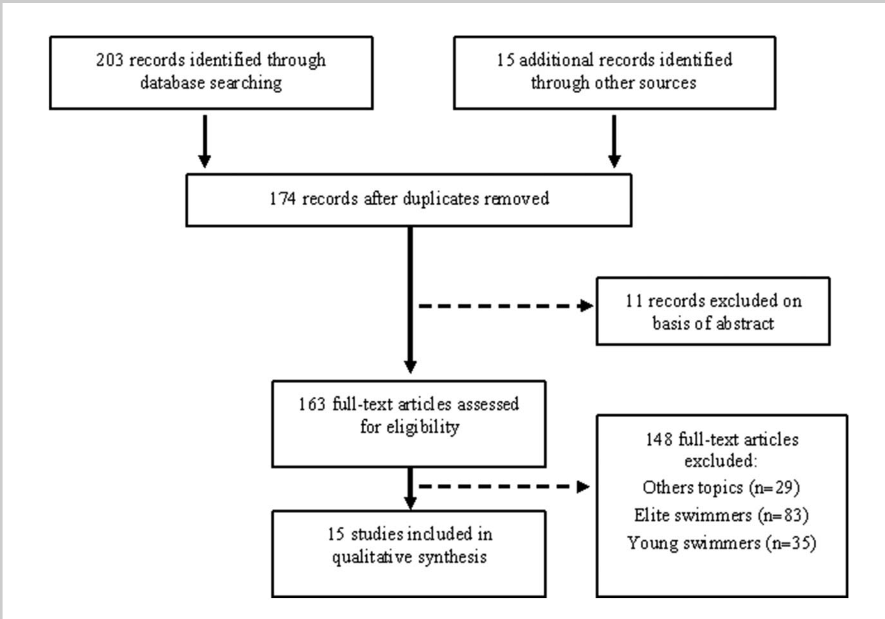

Figure 1. Flow chart of the article selection process.

of them being conducted from 2000 onward (the remaining 2 studies were published in the 1990s), indicating that, in the last 15 years, the interest in this age-group has been increasing. Studies were assigned to each category according to the reported data: performance, energetics, and biomechanics. Studies presenting evidence 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 as well. The single longitudinal study found reported the effects of age and gender on performance.

Quality Assessment

The Quality Index (QI) scores of the articles included in this review ranged from 6 to 13 points (of 32), with a mean score of 10.6 points. The reliability between both reviewers showed an almost perfect agreement (0.94) in the scoring procedure.

The biomechanics was the field that obtained the higher QI score (11.5 points), followed by the performance and energetics (10.8 and 10.5 points, respectively). Among the 5 subscales included in the checklist, the external validity, internal validity (bias and confounding), and power were those with the poorest scores. Regarding the subscale external validity, which addressed the extent to which the findings from the study could be generalized to the population from which the study subjects were derived, none of the selected studies used random sampling to include subjects who would be representative for the entire population. Regarding the subscale bias, which addressed biases in the measurement of the intervention and the outcome, there was no attempt to hide the purpose of the study of the swimmers or to blind those measuring the main outcomes of the intervention. Finally, in the selected studies, the subscale power that attempted to assess whether the negative findings from a study could be due to chance was not indicated. In the first subscale of the checklist (reporting), no study provided a list of the principal confounders and the numbers of the patients lost to follow-up.

Performance

Table 1 summarizes the 4 studies that report the performance variations in master swimmers. All studies were cross-sectional designs, and the overall quality ranged between 9 and 13 points (mean, 10.8 points).

All studies that analyzed the effect of age on swimming performance (Table 2) found that performance impaired with age (2,8,11,24,26,29,30,34,41). Zamparo et al. (41) reported a decrease in performance as a function of age. The race time in a 200-m event increased 72.8% from the younger to the older age-group. A progressive increase in 100 m swimming time was also found with increasing age (29). In this study, the swimming time performance increased 62.2% from the age-group of 25–35 years to the swimmers older than 56 years (29). One of the studies compared elite with master swimmers (24) and reported that the first presented a better performance. Bongard et al. (2) analyzed the distance traveled by men and women of different ages, after 1 hour swimming. The results revealed a significant decrease in swimming distances from the youngest to the oldest age-group in both genders: the swimming distance decreased 84.7% in men, whereas it decreased 105.5% in women. Another study found that the 200-m performance impaired 9–14% between the ages of 35 and 45 years (26). A longitudinal study over a period of 12 years (8) reported that the long-duration and short-duration swimming performance (1,500 m and 50 m, respectively) declined with age. However, the declining rate was greater in long-distance (6–12%) than in short-distance events (3–8%). In this study, the peak of performance in the 1,500-m event was maintained until the midthirties, followed by a progressive decrease until 70 years of age. Rubin et al. (30) reported that, in men, performance impaired in the 50-m (0.34–0.55% per year), 100-m (0.26–0.68% per year), and 1,500-m (0.13–0.55% per

TABLE 1. Summary of the studies about the performance of masters' swimmers.

Authors	Research design	Aim	Subjects	Procedures and outcomes	Findings
Favaro and Lima (11)	Cross-sectional	Verify the relationship between stroke index and performance, and stroke index and age of the swimmers over 50 y	60 male swimmers (25–78 y): +25 y old: 26.78 ± 1.56 y old; +30 y old: 31.68 ± 1.47 y old; +35 y old: 36.8 ± 0.84 y old; +40 y old: 42.13 ± 1.3 y old; +45 y old: 46.5 ± 1.46 y old; +55 y old: 56.86 ± 1.46 y old; +75 y old: 76.50 ± 1.38 y old	Swim 50 m in a Masters Swimming Tour	Time to perform 50-m freestyle: age-group +25 y: 28.08 ± 2.17 s; age-group +30 y old: 28.57 ± 1.84 s; age-group +35 y old: 34.95 ± 6.24 s; age-group +40 y old: 31.43 ± 3.06 s; age-group +45 y old: 32.02 ± 2.62 s; age-group +55 y old: 37.95 ± 6.42 s; age-group +75 y old: 51.34 ± 13.52 s
Reaburn and Mackinnon (28)	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 male competitive masters' swimmers divided into 4 age-groups: 25–35 y: 31.3 y old; 36–45 y: 41.0 y old; 46–55 y: 49.5 y old; >56 y: 67.0 y old	Maximal 100 m freestyle	Time to perform 100-m freestyle: age-group 25–35 y: 59.6 s; age-group 36–45 y: 65.9 s; age-group 46–55 y: 71.7 s; age-group >56 y old: 96.7 s
Zamparo et al. (42)	Cross-sectional	Analyze the determinants of performance in master swimmers	Masters' swimmers with masters world record (25–89 y old)	Analyze master world records for each swimming style and each masters group of age	Time to perform 200-m freestyle: age-group 25–29 y: 112.17 s; age-group 30–34 y: 113.15 s; age-group 35–39 y: 112.84 s; age-group 40–44 y: 113.65 s; age-group 45–49 y: 117.89 s; age-group 50–54 y: 120.34 s; age-group 55–59 y: 124.01 s; age-group 60–64 y: 132.57 s; age-group 65–69 y: 138.53 s; age-group 70–74 y: 146.20 s; age-group 75–79 y: 145.66 s; age-group 80–84 y: 173.74 s; age-group 85–89 y: 193.78 s
Zamparo et al. (43)	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 y old; 8 female, 28.5 ± 8.6 y old	200 m maximal swim trial with a pull-buoy (arms-only) in a 25-m swimming pool	Time to perform 200-m freestyle: male, 187.8 ± 32.7 s; female, 204.4 ± 24.9 s

TABLE 2. Summary of the studies about the effect of age on performance of masters' swimmers.

Authors	Research design	Aim	Subjects	Procedures and outcomes	Findings
Bongard et al. (2)	Cross-sectional	Examine the effects of age and gender on performance	4,271 healthy men and women aged 19–91 y. Men, 45.2 ± 13.0 y old; women, 41.7 ± 13.1 y old	1-hour swimming (2001–2003)	From the youngest decade (19–29 y) to the oldest (≥80 y), the decline in mean performance was 45.9% for men and 51.3% for women
Donato et al. (8)	Longitudinal	Analyze the relationship among age, gender, and endurance swimming performance	319 men and 321 women, 19–85 y old	Analysis of freestyle performance times from the U.S. Masters Swimming Championships over a 12-y period of 1988–1999	Decline in swimming performance with age was greater in long-duration (6–12%) than in short-duration (3–8%) events
Favaro and Lima (11)	Cross-sectional	Verify the relationship between stroke index and performance, and stroke index and age of the swimmers over 50 y	60 male swimmers (25–78 y): +25 y old: 26.78 ± 1.56 y old; +30 y old: 316.8 ± 1.47 y old; +35 y old: 36.8 ± 0.84 y old; +40 y old: 42.13 ± 1.3 y old; +45 y old: 46.5 ± 1.46 y old; +55 y old: 56.86 ± 1.46 y old; +75 y old: 76.50 ± 1.38 y old	Swim 50 m in a masters swimming tour	50 m performance was influenced by aging: +25 y old: 28.08 ± 2.17 s; +30 y old: 28.57 ± 1.84 s; +35 y old: 34.95 ± 6.24 s; +40 y old: 31.43 ± 3.06 s; +45 y old: 32.02 ± 2.62 s; +55 y old: 37.95 ± 6.42 s; +75 y old: 51.34 ± 13.52 s
Mejia et al. (24)	Cross-sectional	Identify the energetics variables related to young masters' and elite performance	8 young masters' swimmers (29.75 ± 3.80 y old) and 12 elite swimmers (20.41 ± 3.20 y old)	7 × 200 m freestyle swim	Elite swimmers presented a better performance than master swimmers
Ransdell et al. (26)	Cross-sectional	Examine age and gender differences in world-record performances of master athletes in swimming	Men and women masters' swimmers (35–50 y old)	Examine masters' world record times in a 25-m pool, for freestyle stroke in 100 m, 200 m, 400 m, 800 m, and 1,500 m distances	200 m performance declined 9–14% between the ages of 35 and 45 y. 200 m world record in men/women: 35 y old: 1.87 min/2.07 min; 40 y old: 1.83 min/2.08 min; 45 y old: 1.92 min/2.10 min; 50 y old: 1.97 min/2.25 min; 55 y old: 2.06 min/2.25 min; 60 y old: 2.17 min/2.63 min; 65 y old: 2.27 min/2.70 min; 70 y old: 2.42 min/2.75 min; 75 y old: 2.47 min/2.95 min; 80 y old: 2.98 min/3.32 min; 85 y old: 3.22 min/3.90 min; 90 y old: 3.67 min/4.42 min

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Reaburn and Mackinnon (28)	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 male competitive masters' swimmers divided into 4 age-groups: 25–35 y: 31.3 y old; 36–45 y: 41.0 y old; 46–55 y: 49.5 y old; >56 y: 67.0 y old	Maximal 100-m freestyle	Increase in best-recorded 100-m swimming time was observed with increasing age: age-group 25–35 y: 59.6 s; age-group: 36–45 y: 65.9 s; age-group 46–55 y: 71.7 s; age-group >56 y: 96.7 s
Rubin et al. (30)	Longitudinal	Examine individual swimmers' data across an average of 23 y	19 male and 26 female masters' swimmers (minimum age of 25 y)	Analyze the results obtained by elite swimmers who participated in competitions for an average of 23 y from the U.S. Masters Swimming and the International Masters Swimming Hall of Fame	50 m performance decline with age in men (0.34–0.55% per y) and women (0.13–0.93% per y)
					100 m performance decline with age in men (0.26–0.68% per y) and women (0.10–1.2% per y)
					50 m performance decline with age in men (0.34–0.55% per y) and women (0.13–0.93% per y)
					1,500 m performance decline with age in men (0.13–0.55% per y) and women (0.04–0.94% per y)
Tanaka et al. (33)	Cross-sectional	Determine the effect of age on performance in adult men and women	Participants in the U.S. Masters Swimming Championships (19–99 y old)	Retrospective analysis of top U.S. Masters freestyle times	Endurance swimming performance decrease with age in men and women
					After 35 and 40 y of age, swimming performance declined until 70 y of age in women and men, respectively
Zamparo et al. (42)	Cross-sectional	Analyze the determinants of performance in master swimmers	Masters' swimmers with masters world record (25–89 y old)	Analyze master world records for each swimming style and each master's group of age	Time to perform 200-m freestyle: age-group 25–29 y: 112.17 s; age-group 30–34 y: 113.15 s; age-group 35–39 y: 112.84 s; age-group 40–44 y: 113.65 s; age-group 45–49 y: 117.89 s; age-group 50–54 y: 120.34 s; age-group 55–59 y: 124.01 s; age-group 60–64 y: 132.57 s; age-group 65–69 y: 138.53 s; age-group 70–74 y: 146.20 s; age-group 75–79 y: 145.66 s; age-group 80–84 y: 173.74 s; age-group 85–89 y: 193.78 s

TABLE 3. Summary of the studies about the energetics of masters' swimmers.*

Authors	Research design	Aim	Subjects	Procedures and outcomes	Findings
Benelli et al. (1)	Cross-sectional	Measure the postcompetition La_{peak} in masters' swimmers of both genders aged between 40 and 79 y and relate it to age and swimming performance	108 masters' swimmers: 56 women (40–49 y: 44.1 ± 3.6 y old; 50–59 y: 53.9 ± 2.7 y old; 60–69 y: 64.6 ± 3.0 y old; 70–79 y: 73.1 ± 2.6 y old). 52 males (40–49 y: 44.2 ± 2.5 y old; 50–59 y: 54.6 ± 3.2 y old; 60–69 y: 64.8 ± 3.1 y old; 70–79 y: 73.0 ± 2.5 y old)	1 testing occasion 5 min after race participating in the 10th World Masters Championship in 2004	Male La_{peak}: 40–49 y: 14.2 ± 2.5 mmol·L^{-1}; 50–59 y: 12.4 ± 2.5 mmol·L^{-1}; 60–69 y: 11.0 ± 1.6 mmol·L^{-1}; 70–79 y: 8.2 ± 2.0 mmol·L^{-1}. Female La_{peak}: 40–49 y: 10.8 ± 2.8 mmol·L^{-1}; 50–59 y: 10.3 ± 2.0 mmol·L^{-1}; 60–69 y: 10.3 ± 1.9 mmol·L^{-1}; 70–79 y: 8.9 ± 3.2 mmol·L^{-1}
Mejias et al. (24)	Cross-sectional	Identify the energetics variables related to young masters and elite performance	8 young masters' swimmers (29.75 ± 3.80 y old)	7 × 200 m freestyle swim	Elite swimmers presented a better performance and a higher v_4, $\dot{V}O_2$max, and E_{tot} than masters' swimmers
			12 elite swimmers (20.41 ± 3.20 y old)		Elite and masters' performance was associated with v_4
Reaburn and Mackinnon (29)	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 male competitive masters' swimmers divided into 4 age-groups: 25–35 y: 31.3 y old; 36–45 y: 41.0 y old; 46–55 y: 49.5 y old; >56 y: 67.0 y old	Maximal 100-m freestyle	La_{peak} may be maintained with high-intensity sprint-swim training as age increases
					La_{peak} after 100-m freestyle (passive recovery): 25–35 y: 14.25 ± 3.34 mmol·L^{-1}; 36–45 y: 15.00 ± 1.28 mmol·L^{-1}; 46–55 y: 15.35 ± 2.41 mmol·L^{-1}; >56 y: 13.05 ± 4.97 mmol·L^{-1}
Zamparo et al. (42)	Cross-sectional	Analyze the determinants of performance in masters' swimmers	Masters' swimmers with masters world record (25–89 y 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

*E_{tot} = total energy expenditure; La_{peak} = maximal blood lactate concentration after exercise; v_4 = velocity at 4 mmol·L^{-1} of blood lactate concentration levels.

Table 4. Summary of the studies about the biomechanics of masters' swimmers.*

Authors	Research design	Aim	Subjects	Procedures and outcomes	Findings
Favaro and Lima (11)	Cross-sectional	Verify the relationship between SI and performance, and SI and age of the swimmers over 50 y	60 male swimmers (25–78 y): +25 y old: 26.78 ± 1.56 y old; +30 y old: 316.8 ± 1.47 y old; +35 y old: 36.8 ± 0.84 y old; +40 y old: 42.13 ± 1.3 y old; +45 y old: 46.5 ± 1.46 y old; +55 y old: 56.86 ± 1.46 y old; +75 y old: 76.50 ± 1.38 y 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 y
Gatta et al. (15)	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 y) divided into 7 age-groups: 50–54 y old; 55–59 y old; 60–64 y old; 65–69 y old; 70–74 y old; 75–79 y old; ≥80 y old	200-m freestyle event in Master World Championship; video-recorded for measurement of the stroke parameters	Aging process affects *SF* more than *SL*
Mejia et al. (24)	Cross-sectional	Identify the kinematics and efficiency variables related to young masters' performance	8 young masters' swimmers (29.75 ± 3.80 y old); 12 elite swimmers (20.41 ± 3.20 y old)	7 × 200 m freestyle swim	Elite swimmers presented a higher *SF* and *SI* than master swimmers
Zamparo (39)	Cross-sectional	Determine the effect of age and gender on η_p	32 males divided into 6 groups: M11: 11.3 ± 1.7 y old; M14: 13.8 ± 0.5 y old; M16: 15.8 ± 0.5 y old; M23: 22.7 ± 2.8 y old; M37: 36.8 ± 4.8 y old; M54: 54.3 ± 4.9 y old. 31 females divided into 6 groups: F10: 9.8 ± 0.5 y old; F12: 12.2 ± 0.4 y old; F16: 15.5 ± 1.0 y old; F23: 22.7 ± 2.7 y old; F33: 33.0 ± 2.6 y old; F45: 45.2 ± 4.8 y old	Swim 50 m at constant velocity and stroke rate and repeat the swim at 3 to 4 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
Zamparo et al. (41)	Cross-sectional	Measure the energy cost of swimming (*C*), the η_p of the arm stroke (η_p), and projected frontal area (A_{eff}) at submaximal aerobic speed	47 male masters' swimmers (31–85 y old) divided into 5 age-groups: M30-40 (36.3 ± 3.0 y old); M40-50 (45.8 ± 3.1 y old); M50-60 (52.9 ± 2.6 y old); M60-70 (62.8 ± 1.8 y old); M70-80 (74.1 ± 5.7 y old)	Swim at a constant, submaximal aerobic speed and a constant stroke rate for about 4 min (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. (43)	Cross-sectional	Explore the relation between arms-only η_p and swimming speed; and between mechanical power output and swimming speed	29 masters' swimmers: 21 male, 33.5 ± 9.1 y old; 8 female, 28.5 ± 8.6 y 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

**SI* = stroke index; *SR* = stroke rate; *SL* = stroke length; *SF* = stroke frequency; η_p = propelling efficiency.

year) events. The same study also reported that, in women, performance decreased in the 50-m (0.13–0.93% per year), 100-m (0.10–1.2%), and 1,500-m (0.04–0.94% per year) events (29). The 50-m performance was influenced by aging (11), with the swimming performance time increasing 82.3% from the younger to the oldest age-group. Tanaka and Seals (34) 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 (1,500 m), the swimming performance time increased 31.7% and 38.7% in men and women, respectively, whereas in short-duration events (50 m) the performance time increased 26.7% in men and 31.7% in women (34).

Energetics

Table 3 presents a summary of the studies that monitored energetics in masters' swimmers, reporting the assessment of the La_{peak}. The overall quality scores ranged between 9 and 13 points, representing a mean score of 10.5 points.

The analyzed studies (1,29) reveal that La_{peak} decreased with advancing age. In the study by Reaburn and Mackinnon (29), La_{peak} decreased 8.4% from the youngest to the oldest age-group. In the study of Benelli et al. (1), the La_{peak} decrease with advancing age was similar but at a different rate: 17.6% in women and 42.2% in men.

It was reported that the v_4, $\dot{V}O_2$max, and the total energy expenditure (E_{tot}) were significantly higher in the elite swimmers than in master swimmers (24). Furthermore, it was reported that v_4, $\dot{V}O_2$max, and E_{tot} impaired with age (24).

Biomechanics

Table 4 presents a summary of the 5 studies that have monitored the biomechanic profile in master swimmers. The overall quality scores ranged between 10 and 13 points, and a mean score of 11.5 points.

All the studies related to the biomechanics profile in master swimmers were cross-sectional studies. Articles reported the *SF* (11,15,39,41,43), *SL* (11,15,39,41,43), *SI* (11), and η_p (39,41,43).

Favaro et al. (11) reported that the swimming stroke (*SL*, *SF*) was influenced by age. The older swimmers presented lower values of *SL*, *SF*, and *SI*. Stroke frequency decreased 21.3% from the youngest to the oldest age-group. The *SL* decreased 26.7% from the youngest to the oldest age-group. Stroke index decreased 56.3% from the youngest to the oldest age-group. Zamparo (39) reported that, in male swimmers, *SF* increased 1.8% from the youngest to the oldest age-group and *SL* and η_p decreased, respectively, 33.5% and 37.5% from the youngest to the oldest age-group. In female swimmers, *SF* decreased 15.6% from the youngest to the oldest age-group and *SL* and η_p decreased, respectively, 31.2% and 28.6% from the youngest to the oldest age-group. Finally, Zamparo et al. (41) reported that *SF* increased 2.4% from the age-group of 30–40 years to the age-group of 70–80 years and *SL* and η_p decreased, respectively, 30.4% and 32.3% from the youngest to the oldest age-group.

Discussion

The aim of this investigation was to summarize evidence on master swimmers allowing characterization of the biomechanics and energetic profiles and performance. The selected studies are relatively recent, with increased interest in this age-group, since the 2000s. 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 the fact that coaches are gaining increasing experience in this age-group (23). 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 who may present limitations or other orthopedic injuries (30). However, we failed to find in the literature longitudinal studies analyzing the energetics and biomechanics profiles, and/or the performance changes over time. The cross-sectional studies have some limitations that may bias the findings, because assessing or comparing different groups and variables at a single moment makes them less informative about the cause-effect relationships. However, the assessment in longitudinal studies implies a data collection during a certain number of occasions, allowing establishment of cause-effect relationships (5). The selected studies mainly report data about swimmers who competed at local or national levels (2,11,24,39,41,43) and swimmers in the top of the national ranking (1,8,15,26,29,30,32,34,42). Regarding performance, the studies found a decline with age (2,8,11,24,26,29,30,34,42). Regarding energetics, not only La_{peak} (1,29), but also v_4, $\dot{V}O_2$max, and E_{tot} (24) decreased with the advancing age. There are few longitudinal studies related to the effects of aging in performance (8,26,30,34).

The majority of the articles, included in this systematic review, presented low quality scores compared with other scientific fields. A similar low quality score (11.68 points) was reported in 28 studies conducted among elite swimmers (5). 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 (29) and the most recent study (24) obtained 10 points while the scores of the studies published between these 2 studies ranged 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 (5), which are hard to be attained in the studies of this area. In fact, it is difficult to obtain random sampling including subjects who would be representative for the entire population, because the number of swimmers with the specific features available for these studies is reduced. Therefore, findings cannot be generalized to the population from which the study subjects were derived. 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.

Considering the 200-m event, the results mentioned previously showed differences in the time required to perform it because of the environment and type of test performed. Thus, the best performance (42) represents the 200-m freestyle master world record, reached in a competition event, whereas the worst time was obtained in a test where only arms were used to swim (43).

All the studies related to performance reported the decline of swimming performance with the advancing of age (i.e., performance time increases). The power and capacity of the immediate (adenosine triphosphate-creatine phosphate), short-term (anaerobic glycolysis), and long-term (oxidative phosphorylation) systems of energy production are the major factors in determining swimming performance (29). With the advancing of age, we found a decrease in the aerobic and anaerobic contributors and/or an increase in energy cost (30,42). As mentioned earlier, cross-sectional and longitudinal studies investigated the changes in maximal aerobic power ($\dot{V}O_2$max) that occurred as a function of age. The cross-sectional studies indicated that $\dot{V}O_2$max decreased by 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, although with a larger variance depending on the level of training. Maximal anaerobic power also decreased with age (42). Although this consensual decrease in aerobic and anaerobic was found, it seems that the rate of decline in swimming performance with age was greater in long-distance than short-distance events, which could mean that physiological determinants of different swim events impair at different rates. Thus, it was suggested that the maximal aerobic capacity exhibits a considerably stepper rate of impairment than the anaerobic power (8). However, despite being slower, the decline of anaerobic power also occurs. The latter one is related 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 (28).

Regarding energy cost, its increase with age is due to either (40) (a) an increase of hydrodynamic resistance, which is because of morphological characteristic changes in body size and density, fat distribution, and skin stiffness, or (b) a decrease of the η_p and overall efficiency. The efficiency depends on the technical skill of the swimmers (36). Considering this, it is important to recall that some of the recruited subjects were not swimmers in their youth, starting to swim only as adults; therefore, a poor technical level should be expected.

In addition to the physiological factors, the decline in performance was also due to the following sociological changes that occur with age with an impact on the external training load: tendency to train with lower exercise intensity (37), professional practical considerations related to their professional work schedules, and familiar responsibilities (18) that do not allow a bigger commitment.

Maximal blood lactate concentration after exercise was the energetic variable used to assess the anaerobic capacity of the swimmers. Maximal blood lactate concentration after exercise is thought to provide useful information on the anaerobic glycolytic activity in working muscles during supramaximal exercise (20). The difference found in La_{peak} values may be attributed to the differences in the test performed to measure it such as its duration, because the contribution of the energy systems depends both on the intensity and duration of the exercise (14). The contribution of the anaerobic lactic energy sources decreases along with the duration of exercise (40). However, in the study of Reaburn and Mackinnon (29) and Benelli et al. (1), the La_{peak} data found in the age-groups of 25–35 years and 40–49 years were similar, although the event was different (100-m vs. 200-m). The fact that may justify the high value found by Benelli et al. (1) 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 (42). 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 aging (28).

The higher values of v_4, $\dot{V}O_2$max, and E_{tot} presented by the elite swimmers compared with masters' swimmers may be explained by the characteristics of the training carried out by masters' swimmers, because the lower volume of training and training loads, predominantly aerobic, will not be enough to improve the energy production systems (24). Moreover, the commitment of masters' swimmers with training is quite different from the one of elite swimmers because of 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 (13), and the most frequently used measure of physiological functional capacity is $\dot{V}O_2$max (34). It is commonly accepted that physical activity increases $\dot{V}O_2$max (7), as evidenced by the data reported in several studies, showing that $\dot{V}O_2$max of active and athletic subjects was significantly greater than sedentary subjects of similar age (10,12,19,25,38). However, the role of exercise on the age-associated decline of $\dot{V}O_2$max is highly controversial (13). Several studies reported a rate of decline of 10% per decade after the age of 25 years in healthy sedentary individuals (4,10,12,34). Moreover, it has been proposed that continued exercise training may slow the rate of decline of $\dot{V}O_2$max at a rate of 5% per decade rather than the 10% per decade mentioned earlier (3,16). On the contrary, some studies reported that the rate of decline of $\dot{V}O_2$max was similar in athletic and sedentary subjects (19,33). Although it was expected that age per se would contribute to the decline of $\dot{V}O_2$max, it seems 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 would be important to maintain a vigorous physical activity to mitigate the age-related decrease in $\dot{V}O_2$max (13,17). For all the reasons mentioned earlier, $\dot{V}O_2$max 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 (10,12). Considering this, Bongard et al. (2) suggested that masters' swimmers have a lower cardiovascular risk than their less physically active counterparts.

The changes observed in the biomechanics variables, within a season, are important once they allow analyzing the effectiveness of the stroke mechanics. To accomplish this, *SF*, *SL*, *SI*, and η_p were used. The analysis of the 6 studies showed that Favaro et al. (11) and Zamparo et al. (41) obtained the outlier values of *SF* and *SL*. One reason may be the different protocols 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. (11) 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*, whereas at submaximal velocity, v is achieved by a smaller *SF* and a larger *SL* (41). The higher value of *SL* reported by Zamparo et al. (41) may be attributed to the test performed (swim for 4 minutes at a constant submaximal speed) and, consequently, to the v reached in the test, once *SL* increases with the increase in distance being larger at slow swimming speeds and tends to decrease at maximal speed. Finally, the lower η_p value obtained by Zamparo et al. (43) may be explained by the intensity of the bout. Swimmers performed 200 m at a maximal velocity, whereas the data by Zamparo (39) were collected at a submaximal and constant speed. Propelling efficiency is proportional to the distance covered per stroke and tends to decrease at higher speeds (39). The lower v, *SF*, and *SI* values found in masters' compared with elite swimmers may be explained by the lower mechanical power and muscle strength of the former (24).

Favaro et al. (11) reported that the biomechanics parameters (*SL*, *SF*) were influenced by age, because the older swimmers presented lower values of *SL*, *SF*, and *SI*. Stroke length and *SF* depend on muscle strength and the ability to exert powerful and effective stroke in water, and, as we mentioned earlier, with the advancing of age, a decrease in the muscle mass and the type II muscle fibers atrophy occurs.

Conclusions

Age influences the performance, energetics, and biomechanics of master swimmers. Biomechanics variables, such as the *SF*, *SL*, and η_p, impaired with age. Performance also impairs with age. Male swimmers delivered better performances than female counterparts, although this difference tends to decrease in long-distance events. This review shows the lack of longitudinal studies, assessing the changes in energetics and biomechanics over time and how it may influence the performance. Hence, with no insight into such relationships over time, it is more challenging to design effective training programs for master swimmers.

Practical Applications

The evidence gathered in this review may be useful for both swimmers and coaches. Indeed, the stability and change with age observed in some variables can be an important tool for training and performance control. Age influences the performance, energetics, and biomechanics parameters. Therefore, the training should aim to preserve the energetic factors as much as possible and, concurrently, develop the technical skills. Thus, training should include a higher percentage of technical drills to enhance the technical performance of the swimmers. The focus would be on the association of technical training with aerobic and anaerobic tasks, allowing the swimmer to increase technical efficiency. Future studies should consider selecting more cutting-edge and insightful research designs (e.g., randomized control groups) to improve the body of knowledge.

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