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

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Abstract

Purpose: Summarize evidence on masters' swimmers energetics, biomechanics and performance, gathered in selected studies.

Methods: An expanded search was conducted on six 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 two independent reviewers. The studies were thereafter classified into three domains according to the reported data: performance (10 studies), energetics (4 studies) and biomechanics (6 studies).

Results: The selected 15 articles included in this review presented low QI scores (mean score of 10.47 points). The biomechanics domain obtained the higher QI (11.5 points), followed by energetics and performance (10.6 and 9.9 points, respectively). Stroke frequency (*SF*) and stroke length (*SL*) were both influenced by aging, although *SF* is more affected than *SL*. Propelling efficiency (η_p) decreased with age. Swimming performance declined with age. The performance declines with age having male swimmers delivered better performances than female counterparts, although this difference tends to be narrow in long-distance events.

Conclusions: One single longitudinal study is found in the literature reporting the changes in performance over time. 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 ok knowledge (reflected in the amount and quality of the papers published) on the changes in biomechanics, energetics and performance of master swimmers over time.

Practical Applications: The training programs for this age-groups should be aiming to preserve the energetics as much as possible and, concurrently improving 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.

Keywords: Swimming, aging, technique, physiology, swim stroke, performance

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 (3500 athletes) until the last held in 2015 in Kazan (6318 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, i.e. 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 towards increasing physical activity in adulthood, it is important to understand the relationship between age and physical performance as well as identifying 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-term frame (6). Another interesting topic of investigation is the gender gap in master swimmers considering that, compared to 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 energetic 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, assisting coaches in their training prescription, and highlighting areas for further research**.** For this, a systematic review was done, 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 papers published on this topic. Based on inclusion and exclusion criteria, a selected number of papers were kept for further analysis.

Search Strategy

An extensive literature search was conducted, from January 1st 1970 until March 31st 2014, to identify the studies in which biomechanics and energetics variables were reported for master swimmers. This was done running searches on databases (PubMed, ISI Web of Knowledge, Index Medicus, Medline, Scopus, and Sport Discus) using the keywords “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 was done by using the papers’ 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 mmol·l^{-1} of blood lactate concentration levels (v_4), maximal oxygen consumption (VO_{2max}), and maximal blood lactate concentration after exercise (La_{peak}). The biomechanics variables were: stroke frequency (*SF*), stroke length (*SL*), stroke index (*SI*), and propelling efficiency (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 old (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 three main groups: i) performance; ii) energetics; iii) 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 due to the absence of a validated quality assessment tool suitable for sports performance. Two independent reviewers were briefed on how to do the 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 papers. 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 i) $K \leq 0$ represents no agreement; ii) $0 < K \leq 0.19$ poor agreement; iii) $0.20 < K \leq 0.39$ fair agreement; iv) $0.40 < K \leq 0.59$ moderate agreement; v) $0.60 < K \leq 0.79$ substantial agreement, and vi) $0.80 < K \leq 1.00$ almost perfect agreement.

RESULTS

Our search identified 163 relevant articles of which 148 did not meet the inclusion criteria (Figure 1). The reasons for exclusion were: being focused on other topics, such as body composition, anthropometric characteristics, skeletal muscle mass, and strength conducted with elite swimmers, and participants from 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).

Figure 1

The studies focusing on the energetics, biomechanics, and performance domains in masters' swimmers are recent, being most of them conducted from 2000 onwards (the remaining two 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 was 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 papers included in this review ranged from 6 to 13 points (out 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 five sub-scales included in the checklist, the external validity, internal validity (bias and confounding), and power were those with the poorest scores. Regarding the sub-scale 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 that would be representative for the entire population. The sub-scale 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 sub-scale power which attempted to assess whether the negative findings from a study could be due to chance, was not indicated. In the first sub-scale of the checklist (reporting), no study provided a list of the principal confounders and the numbers of the patients lost to follow-up.

Performance

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

Table 1

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 200 m event increased 72.8 % from 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 25-35 years-old to the swimmers older than 56 years-old (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 one hour swimming. The results revealed a significant decrease in swimming distances from the youngest to the oldest age-group in both genders: in men the swimming distance decreased 84.7% whereas in women decreased 105.5%. 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 and short duration swimming performance (1500 m and 50 m, respectively) declined with age. However, the declining rate was greater in a long-distance (6 to 12%) than in a short-distance events (3 to 8%). In this study, the peak of performance in the 1500 m event was maintained until the mid-thirties, followed by a progressive decrease until 70 years-old. Rubin et al. (30) reported that, in men, performance impair in the 50 m (0.34%-0.55% per year), 100 m (0.26%-0.68% per year), and 1500 m (0.13%-0.55% per year) 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 1500 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 (1500 m), the swimming performance time increased 31.7% and 38.7% in men and women, respectively, whereas in short-duration events (50 m) performance time increased 26.7% in men and 31.7% in women (34).

**Table 2 **

Energetics

Table 3 presents a summary of the studies that monitored energetics in masters' swimmers, reporting the assessment of the maximal blood lactate concentration after exercise (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 velocity at 4 mmol·l^{-1} of blood lactate concentration (v_4), VO_{2max} and the total energy expenditure (E_{tot}) were significantly higher in the elite swimmers than in master swimmers (24). Furthermore, it was reported that v_4, VO_{2max} and E_{tot} impaired with age (24).

Table 3

Biomechanics

Table 4 presents a summary of the five 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 with the biomechanics profile in master swimmers were, cross-sectional studies. Papers reported the stroke frequency (*SF*) (11,15,39,41,43), stroke length (*SL*) (11,15,39,41,43), stroke index (*SI*) (11) and propelling efficiency (η_p) (39,41,43).

Favaro et al. (11) reported that the swimming stroke (*SL*, *SF*) were influenced by age. The older swimmers presented lower values of *SL*, *SF* and *SI*. *SF* decreased 21.3% from the youngest to the oldest age-group. The *SL* decreased 26.7% from the youngest to the oldest age-group. *SI* 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; *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; *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 30-40 years old to the age-group 70-80 years old; *SL* and η_p decreased, respectively, 30.4% and 32.3% from the youngest to the oldest age-group.

Table 4

DISCUSSION

The aim of this investigation was to summarize evidence on master swimmers allowing characterizing the biomechanics and energetic profiles and performance. The selected studies are relatively recent, with an increased interest in this age group, since 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 that 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, since assessing or comparing different groups and variables at a single moment, makes them less informative about the cause-effect relationships. On the other hand, the assessment in longitudinal studies implies a data collection during a certain number of occasions, allowing establishing cause-effect relationships (5). The selected studies mainly report data about swimmers that 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, VO_{2max} and E_{tot} (24) decreased with the advancing age. There are few longitudinal studies related with the effects of aging in performance (8,26,30,34).

Quality Assessment

The majority of the articles, included in this systematic review, presented low quality scores compared to other scientific fields. A similar low quality score (11.68 points) was reported in 28 studies conducted with 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 two 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 attain in the studies of this area. In fact, it is difficult to obtain random sampling, including subjects that would be representative for the entire population, since the number of swimmers with the specific features available for these studies is reduced. Therefore, findings cannot be generalized to the population from which the study subjects were derived. In order to minimize this limitation, convenience samples are used. Considering this, the development of a more adequate list, adjusted to the characteristics of this field of study may be necessary or, whenever possible, swimming researchers should consider the aspects mentioned previously to improve the quality of the studies.

Performance

Considering 200 m event, the results mentioned previously showed differences in the time required to perform it, due to 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, while the worst time was obtained in a test where only arms were used to swim (43).

All the studies related with performance reported the decline of swimming performance with advancing of age (i.e. performance time increases). The power and capacity of the immediate (ATP-PCr), short-term (anaerobic glycolysis), and long-term (oxidative phosphorylation) systems of energy production are the major factors in determining swimming performance (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 (section 4.2), cross-sectional and longitudinal studies investigated the changes in maximal aerobic power (VO_{2max}) that occurred as a function of age. The cross-sectional studies indicated that VO_{2max} 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, though 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 happens. The later 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 either (40): (i) an increase of hydrodynamic resistance, due to morphological characteristics changes in body size and density, fat distribution, and skin stiffness, or; (ii) a decrease of the propelling efficiency and overall efficiency. The efficiency depends on the technical skill of the swimmers (36). Considering this, it is important to recall that some of recruited subjects were not swimmers in their youth, starting to swim only in adults, so a poor technical level should be expected.

In addition to the physiological factors, the decline in performance was also due to 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.

Energetics

La_{peak} was the energetic variable used to assess the anaerobic capacity of the swimmers. La_{peak} is thought to provide useful information on the anaerobic glycolytic activity in working muscles during supramaximal exercise (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, as 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 Reaburn and Mackinnon (29) and Benelli et al. (1) the La_{peak} data found in the age-groups 25-35 years old and 40-49 years old was similar, although the event was different (100-m vs. 200-m). The fact that may justify the high value found by Benelli et al. (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 ageing (28).

The higher values of v_4, VO_{2max} and total energy expenditure (E_{tot}) presented by the elite swimmers compared to masters' may be explained by the characteristics of the training carried out by masters' swimmers, as the lower volume of training and training loads, predominantly aerobic, will not be enough to improve the energy production systems (24).

Moreover, the commitment of masters' swimmers with training is quite different from the one of elite swimmers, due to different goals and professional/familiar compromises.

The quality of life, cardiovascular disease, all-cause mortality, and the ability to perform the tasks of the daily life and the ease with which these tasks can be performed (i.e., physiological functional capacity) depend largely on the maintenance of sufficient aerobic capacity and strength (13) and the most frequently used measure of physiological functional capacity is VO_{2max} (34). It is commonly accepted that physical activity increases VO_{2max} (7), as evidenced by the data reported in several studies, showing that VO_{2max} 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 VO_{2max} is highly controversial (13). Several studies reported a rate of decline of 10% per decade after the age of 25 years old in healthy sedentary individuals (4,10,12,34). Moreover, it has been proposed that continued exercise training may slow the rate of decline of VO_{2max} at a rate of 5% per decade rather than the 10% per decade mentioned earlier (3,16). On the contrary, some studies reported that the rate of decline of VO_{2max} was similar in athletic and sedentary subjects (19,33). Although, it was expected that age per se would contribute to the decline of VO_{2max}, it appears that the decrease in the practice of regular aerobic exercise may result in a higher rate of decline that could result in a loss of independence in carrying out daily tasks. Thus, it would be important to maintain a vigorous physical activity to mitigate the age-related decrease in VO_{2max} (13,17). For all the reasons mentioned earlier, VO_{2max} is considered a good health indicator, once the decrease in maximal aerobic capacity with age has a number of physiological and clinical implications such as increased risks for cardiovascular and all-cause mortality, disability, and reductions in cognitive function, quality of life, and independence (10,12). Considering this, Bongard et al. (2) suggested that masters' swimmers have a lower cardiovascular risk than their less physically active counterparts.

Biomechanics

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 six studies showed that Favaro et al. (11) and Zamparo et al. (41) obtained the outliers 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*, while 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 four minutes at a constant submaximal speed) and, consequently, to the *v* reached in the test, once *SL* increases with the distance increase, 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 while the data by Zamparo (39) was collected at a submaximal and constant speed. η_p 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 to 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, as the older swimmers presented lower values of *SL*, *SF* and *SI*. *SL* 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 on such relationships over time, it is more challenging to designing 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. So the training should be aimming 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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CONFLICT OF INTEREST

Authors do not have any conflict of interest regarding this study.

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FIGURES

Figure 1. Flow chart of the article selection process

TABLES

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

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

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

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

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

Authors	Research design	Aim	Subjects	Procedures and outcomes	Findings
Favaro et al. (11)	Cross-sectional	Verify the relationship between stroke index and performance, and stroke index and age of the swimmers over fifties.	60 male swimmers (25-78 years) +25 yrs old: 26.78±1.56 yrs old +30 yrs old: 316.8±1.47 yrs old +35 yrs old: 36.8±0.84 yrs old +40 yrs old: 42.13±1.3 yrs old +45 yrs old: 46.5±1.46 yrs old +55 yrs old: 56.86±1.46 yrs old +75 yrs old: 76.50±1.38 yrs old	Swim 50 m in a Masters Swimming Tour	Time to performed 50 m freestyle: Age-group +25 yrs old: 28.08±2.17 s Age-group +30 yrs old: 28.57±1.84 s Age-group +35 yrs old: 34.95±6.24 s Age-group +40 yrs old: 31.43±3.06 s Age-group +45 yrs old: 32.02±2.62 s Age-group +55 yrs old: 37.95±6.42 s Age-group +75 yrs old: 51.34±13.52 s
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 males competitive masters swimmers divided in four age groups: 25-35: 31.3 yrs old 36-45: 41.0 yrs old 46-55: 49.5 yrs old >56: 67.0 yrs old	Maximal 100 m freestyle	Time to performed 100-m: Age-group 25-35 yrs old: 59.6 s Age-group 36-45 yrs old: 65.9 s Age-group 46-55 yrs old: 71.7 s Age-group >56 yrs old: 96.7 s
Zamparo et al. (42)	Cross-sectional	Analyze the determinants of performance in master swimmers	Masters swimmers with masters world record (25-89 yrs old)	Analyze master world records for each swimming style and each masters group of age	Time to performed 200-m freestyle: Age-group 25-29 yrs old: 112.17 s Age-group 30-34 yrs old: 113.15 s Age-group 35-39 yrs old: 112.84 s Age-group 40-44 yrs old: 113.65 s

					Age-group 45-49 yrs old: 117.89 s Age-group 50-54 yrs old: 120.34 s Age-group 55-59 yrs old: 124.01 s Age-group 60-64 yrs old: 132.57 s Age-group 65-69 yrs old: 138.53 s Age-group 70-74 yrs old: 146.20 s Age-group 75-79 yrs old: 145.66 s Age-group 80-84 yrs old: 173.74 s Age-group 85-89 yrs old: 193.78 s
Zamparo et al. (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 yrs old 8 female - 28.5±8.6 yrs old	200 m maximal swim trial with a pull-buoy (arms only) in a 25 m swimming pool	Time to performed 200-m: Male - 187.8±32.7 s Female - 204.4±24.9 s

Table 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	4271 healthy men and women aged 19-91 years Men - 45.2±13.0 yrs old Women - 41.7±13.1 yrs old	One hour swimming (2001-2003)	From the youngest decade (19-29 yrs) to the oldest (≥80 yrs) the decline in mean performance was 45.9% for men and 51.3% for women
Donato et al. (8)	Longitudinal	Analyze the relationship among age, gender, and endurance swimming performance	319 men and 321 women 19-85 yrs old	Analysis of freestyle performance times from the US MS Championships over a 12years period of 1988–1999	Declines in swimming performance with age were greater in long-duration (6 to 12%) than in short-duration (3 to 8%) events.
Favaro et al. (11)	Cross-sectional	Verify the relationship between stroke index and performance, and stroke index and age of the swimmers over fifties	60 male swimmers (25-78 years) +25 yrs old: 26.78±1.56 yrs old; +30 yrs old: 316.8±1.47 yrs old; +35 yrs old: 36.8±0.84 yrs old; +40 yrs old: 42.13±1.3 yrs old; +45 yrs old: 46.5±1.46 yrs old; +55 yrs old: 56.86±1.46 yrs old; +75 yrs old: 76.50±1.38 yrs old	Swim 50 m in a Masters Swimming Tour	50 m performance was influenced by aging +25 yrs old: 28.08±2.17 s +30 yrs old: 28.57±1.84 s +35 yrs old: 34.95±6.24 s +40 yrs old: 31.43±3.06 s +45 yrs old: 32.02±2.62 s +55 yrs old: 37.95±6.42 s +75 yrs old: 51.34±13.52 s
Mejia et al. (23)	Cross-sectional	Identify the energetics variables related to young masters' and elite performance	8 young masters swimmers (29.75±3.80 yrs old) and 12 elite swimmers (20.41±3.20 yrs old)	7x200 m freestyle swim	Elite swimmers presented a better performance than master swimmers

Ransdell et al. (25)	Cross-sectional	Examine age and gender differences in world-record performances of master athletes in swimming	Men and women masters' swimmers (35-50 yrs old)	Examine masters' world record times in a 25 m pool, for freestyle stroke in 100m, 200m, 400, 800m and 1500m distances	200 m performance declined 9-14% between the ages of 35 and 45 years 200 m world record in men /women: 35 yrs old: 1.87 minutes / 2.07 minutes 40 yrs old: 1.83 minutes / 2.08 minutes 45 yrs old: 1.92 minutes / 2.10 minutes 50 yrs old: 1.97 minutes / 2.25 minutes 55 yrs old: 2.06 minutes / 2.25 minutes 60 yrs old: 2.17 minutes / 2.63 minutes 65 yrs old: 2.27 minutes / 2.70 minutes 70 yrs old: 2.42 minutes / 2.75 minutes 75 yrs old: 2.47 minutes / 2.95 minutes 80 yrs old: 2.98 minutes / 3.32 minutes 85 yrs old: 3.22 minutes / 3.90 minutes 90 yrs old: 3.67 minutes / 4.42 minutes
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 males competitive masters swimmers divided in four age groups: 25-35: 31.3 yrs old 36-45: 41.0 yrs old 46-55: 49.5 yrs old >56: 67.0 yrs old	Maximal 100 m freestyle	Increase in best recorded 100-m swimming time was observed with increasing age Age-group 25-35 yrs old: 59.6 s Age-group: 36-45 yrs old: 65.9 s Age-group 46-55 yrs old: 71.7 s Age-group >56 yrs old: 96.7 s

Rubin et al. (29)	Longitudinal	Examine individual swimmers' data across an average of 23 years	19 male and 26 female masters swimmers (minimum age of 25 yrs old)	Analyze the results obtained by elite swimmers who participated in competitions for an average of 23 years from US Masters Swimming and the International Masters Swimming Hall of Fame	50 m performance decline with age in men (0.34%-0.55% per year) and women (0.13%-0.93% per year) 100 m performance decline with age in men (0.26%-0.68% per year) and women (0.10%-1.2% per year) 50 m performance decline with age in men (0.34%-0.55% per year) and women (0.13%-0.93% per year) 1500 m performance decline with age in men (0.13%-0.55% per year) and women (0.04%-0.94% per year)
Tanaka and Seals (33)	Cross-sectional	Determine the effect of age on performance in adult men and women	Participants in US Masters Swimming Championships (19-99 yrs old)	Retrospective analysis of top US Masters freestyle times	Endurance swimming performance decrease with age in men and women After 35 and 40 years of age swimming performance declined until 70 years of age in women and men, respectively
Zamparo et al. (42)	Cross-sectional	Analyze the determinants of performance in master swimmers	Masters swimmers with masters world record (25-89 yrs old)	Analyze master world records for each swimming style and each master's group of age	Time to performed 200-m freestyle: Age-group 25-29 yrs old: 112.17 s Age-group 30-34 yrs old: 113.15 s Age-group 35-39 yrs old: 112.84 s Age-group 40-44 yrs old: 113.65 s

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Age-group 70-74 yrs old: 146.20 s
Age-group 75-79 yrs old: 145.66 s
Age-group 80-84 yrs old: 173.74 s
Age-group 85-89 yrs old: 193.78 s

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

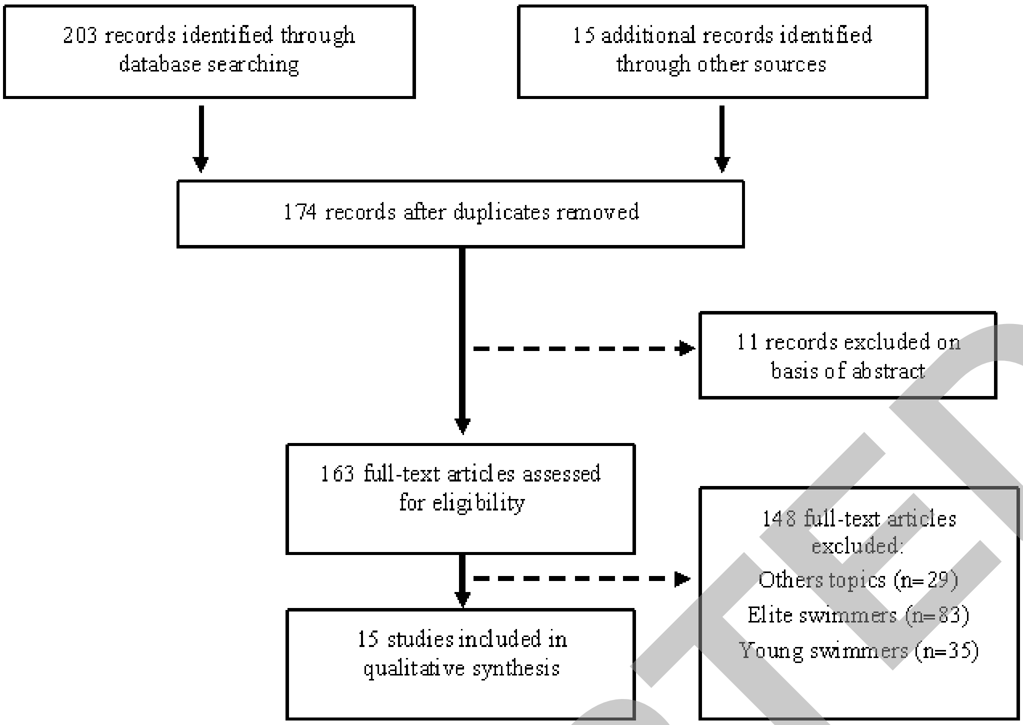
Authors	Research design	Aim	Subjects	Procedures and outcomes	Findings
Benelli et al. (1)	Cross-sectional	Measure the post-competition blood lactate concentration (La_{peak}) in masters swimmers of both genders aged between 40-79 years and relate it to age and swimming performance	108 masters swimmers 56 females (40-49: 44.1±3.6 yrs old; 50-59: 53.9±2.7 yrs old; 60-69: 64.6±3.0 yrs old; 70-79: 73.1±2.6 yrs old) 52 males (40-49: 44.2±2.5 yrs old; 50-59: 54.6±3.2 yrs old; 60-69: 64.8±3.1 yrs old; 70-79: 73.0±2.5 yrs old)	1 testing occasion 5 minutes after race participating in the 10th World Masters Championship in 2004	Male La_{peak}: 40-49: 14.2±2.5 $mmol \cdot l^{-1}$ 50-59: 12.4±2.5 $mmol \cdot l^{-1}$ 60-69: 11.0±1.6 $mmol \cdot l^{-1}$ 70-79: 8.2±2.0 $mmol \cdot l^{-1}$ Female La_{peak}: 40-49: 10.8±2.8 $mmol \cdot l^{-1}$ 50-59: 10.3±2.0 $mmol \cdot l^{-1}$ 60-69: 10.3±1.9 $mmol \cdot l^{-1}$ 70-79: 8.9±3.2 $mmol \cdot l^{-1}$
Mejias et al. (23)	Cross-sectional	Identify the energetics variables related to young masters and elite performance	8 young masters swimmers (29.75±3.80 yrs old) 12 elite swimmers (20.41±3.20 yrs old)	7x200 m freestyle swim	Elite swimmers presented a better performance and a higher v_4, VO_{2max}, and E_{tot} than masters swimmers. Elite and masters performance was associated with v_4
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 males competitive masters swimmers divided in four age groups: 25-35: 31.3 yrs old 36-45: 41.0 yrs old 46-55: 49.5 yrs old	Maximal 100 m freestyle	La_{peak} may be maintained with high-intensity sprint-swim training as age increases. La_{peak} following 100 m freestyle (passive recovery): 25-35: 14.25±3.34 $mmol \cdot l^{-1}$ 36-45: 15.00±1.28 $mmol \cdot l^{-1}$ 46-55: 15.35±2.41 $mmol \cdot l^{-1}$

			>56: 67.0 yrs old		>56: 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 yrs old)	Assessment of the metabolic power required in swimming races and the metabolic power available	Masters swimmers' performance declined due to the decrease in metabolic power available and increase in energy cost.

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

Authors	Research design	Aim	Subjects	Procedures and outcomes	Findings
Favaro et al. (11)	Cross-sectional	Verify the relationship between stroke index and performance, and stroke index and age of the swimmers over fifties	60 male swimmers (25-78 years) +25 yrs old: 26.78±1.56 yrs old; +30 yrs old: 316.8±1.47 yrs old; +35 yrs old: 36.8±0.84 yrs old; +40 yrs old: 42.13±1.3 yrs old; +45 yrs old: 46.5±1.46 yrs old; +55 yrs old: 56.86±1.46 yrs old; +75 yrs old: 76.50±1.38 yrs old	Swim 50 m in a Masters Swimming Tour	*SR* and *SL* were influenced by aging. *SI* can be used for the prediction 50 m performance of freestyle above 50 years
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 years) divided in 7 age-groups: 50-54 yrs old; 55-59 yrs old; 60-64 yrs old; 65-69 yrs old; 70-74 yrs old; 75-79 yrs old; ≥80 yrs old	200 m freestyle event in Master World Championship; video-recorded for measurement of the stroke parameters	Ageing process affects *SF* more than *SL*
Mejia et al. (23)	Cross-sectional	Identify the kinematics and efficiency variables related to young masters' performance	8 young masters swimmers (29.75±3.80 yrs old) 12 elite swimmers (20.41±3.20 yrs old)	7x200 m freestyle swim	Elite swimmers presented a higher *SF*, and *SI* than master swimmers
Zamparo (39)	Cross-sectional	Determine the effect of age and gender on propelling efficiency (η_p)	32 males divided into 6 groups: M11: 11.3±1.7 yrs old; M14: 13.8±0.5 yrs old; M16: 15.8±0.5 yrs old; M23: 22.7±2.8 yrs old; M37: 36.8±4.8 yrs old; M54:	Swim 50 m at constant velocity and stroke rate and repeat the swim at three to four incremental speeds (in a 50 m swimming pool)	η_p decreased with age. M11: 0.32±0.04 M14: 0.36±0.03 M16: 0.40±0.04 M23: 0.38±0.06

			54.3±4.9 yrs old 31 females divided into 6 groups: F10: 9.8±0.5 yrs old; F12: 12.2±0.4 yrs old; F16: 15.5±1.0 yrs old; F23: 22.7±2.7 yrs old; F33: 33.0±2.6 yrs old; F45: 45.2±4.8 yrs old		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 propelling efficiency of the arm stroke (η_p) and projected frontal area (A_{eff}) at submaximal aerobic speed	47 male masters' swimmers (31-85 years old) divided into five age-groups: M30-40 (36.3±3.0 yrs old) M40-50 (45.8±3.1 yrs old) M50-60 (52.9±2.6 yrs old) M60-70 (62.8±1.8 yrs old) M70-80 (74.1±5.7 yrs old)	Swim at a constant submaximal, aerobic speed and a constant stroke rate for about 4 minutes (in a 25 m swimming pool)	*SF* (Hz) / *SL* (m) / η_p M30-40: 0.41 Hz / 2.27 m / 0.34 M40-50: 0.47 Hz / 2.10 m / 0.32 M50-60: 0.46 Hz / 1.86 m / 0.28 M60-70: 0.44 Hz / 1.47 m / 0.22 M70-80: 0.42 Hz / 1.58 m / 0.23
Zamparo et al. (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 yrs old 8 female - 28.5±8.6 yrs old	200 m maximal swim trial with a pull-buoy (arms only) in a 25 m swimming pool	Maximal speed depends on η_p and on maximal power output


203 records identified through database searching
15 additional records identified through other sources
174 records after duplicates removed
11 records excluded on basis of abstract
163 full-text articles assessed for eligibility
148 full-text articles excluded:
Others topics (n=29)
Elite swimmers (n=83)
Young swimmers (n=35)
15 studies included in qualitative synthesis