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Review

Unveiling biophysical characteristics in different triathlon race formats: a systematic review

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Abstract: Triathlon is an endurance sport growing in popularity. There are various triathlon race formats that require different types of effort. However, there is a lack of information regarding the integrated physiological and biomechanical characteristics of the different race formats. Thus, our aim of this systematic review was to synthesize the biophysical characteristics of different triathlon race formats. The methodology was conducted following PRISMA 2020 guidelines searching Web of Science, PubMed, and Scopus databases. Eligibility criteria were defined for the PICOS strategy (healthy mature triathletes, biomechanical and/or physiological assessment, continuous efforts simulating either segments of races or full races, cardiovascular demand, aero/hydrodynamic, and a technical profile). The quality index was assessed with the Downs and Black Assessment Checklist. A total of 8560 articles were screened, of which 30 satisfied the inclusion criteria, and these were grouped in short-distance race formats (n = 18) and middle-distance race formats (n = 12). Overall, studies showed a quality score of 11.86 ± 1.05 points. The biophysical profile of triathlon is influenced by multiple factors, including race distance, competitive level, segment-specific demands, and sex. Within the literature, there is a lack of analysis concerning other race formats, such as long-distance events (e.g., Ironman and Deca-Ironman), as well as new emerging race formats (e.g., Supertri, Arena Supertri E World Triathlon Championship, or T100).

Keywords: triathlon; biomechanics; physiology; race formats; distances; swimming; running; cycling

1. Introduction

Triathlon was created in the early 1970s and has grown in popularity since the 2000 Summer Olympics Games held in Sydney [1,2]. This multidisciplinary sport consists of the continuous effort of swimming, cycling, and running [3]. Based on the evolution of the triathlon and its social interest, different race formats were created, varying from Super Sprint to Ultra-Ironman's (e.g., Deca-Ironman). Regardless of the competitive distance, the triathlon effort is predominantly endurance, which leads to sustaining a high mechanical power or load during prolonged exercise [4].

Triathlon race formats are characterized based on distance and the number of times that each segment is performed [5]. Regarding the typical swim, cycle, and run sequence, the distance of each segment varies from shorter formats like Super Sprint (400 m swim, 10 km cycle, 2.5 km run), Sprint (750 m swim, 20 km cycle, 5 km run), middle-distance like Olympic distance (1.5 km swim, 40 km cycle, 10 km run), Half-Ironman (70.3) (1.9 km swim, 90 km cycle, 21.1 km run), and the T100 (2 km swim, 80 km cycle, 18 km run) or longer race formats Ironman (140.6) (3.8 km swim, 180 km cycle, 42.2 km run). There are race formats that take the triathlete more than one day to complete, such as Deca-Ironman, which consists of the sum of 10 Ironman races in a row (38 km swim, 18000 km cycle, 422 km run). At the Tokyo 2020 Summer Olympic Games (held in 2021), the Mixed Team Relay became part of the official Olympic program, following its introduction to the international triathlon stage several years earlier [6].

Race formats can also differ regarding the number of times that each segment is performed [7]. For instance, a new race format entitled Supertri was introduced in 2017 (previously called Super League Triathlon), consisting of a continuous effort including three rounds of a 300 m swim, 4 km bike, and a 1.6 km run without any breaks. Notwithstanding, with the increasing visibility of virtual sports due to the pandemic, in 2021, the Arena Supertri E World Triathlon Championship format was born [7]. It is similar to the outdoor Supertri, 3 rounds of 200 m indoor pool swim, 4 km static bike and a 1 km treadmill run, but with intervals after each round, and the order of the segment changes at the end of each round [8]. This new format is growing in popularity due to being more engaging for the viewers and more dynamic for triathletes. Due to the complex interactions between segments and transitions, it becomes crucial to know the specificities and effort demands of the different race formats.

The triathlon training has evolved over the years requiring a holistic approach to planning and training management, leading to some research groups having a "Biophysical" interest in performance [9,10]. Biophysics is a critical area in sport sciences that consolidates the physiological and biomechanical domains and has been applied to sports such as tennis [11,12] and swimming [13]. In the specific case of triathlon, those were made testing energy systems [14], movement mechanics [15], and the subsequent effects between disciplines [16–18]. Moreover, some researchers tried to test secondary factors that could influence race dynamics like air/water temperatures [19,20], race courses [21], types of equipment used [22,23], psychological effects [24,25], nutrition and hydration, [26−28], training methodology [29−31], anthropometric and genetic factors [32−34], or micro-variables in the biochemical domain [35−38]. Although those are great studies to deal with and helpful for the training process, there is a lack of consolidated and detailed information about the key biomechanical and physiological factors that influence performance in each race format.

The available reviews on triathlon are few and focus on specific aspects like nutrition [39,40], injury prevention [41−43], psychology [44], cytokine profile [45], equipment (e.g., wetsuit [46,47]), or physiology [48,49]. There are reviews entailing information about biophysical parameters but just in swimming [50], swim to cycle adaptations [51], or cycle to run adaptations [52]. With the evolution of sport and the appearance of new race formats, there is a need to update the state of the art about the biophysical demands of a complete triathlon race. A systematic review encompassing biomechanical and physiological variables in different formats could be useful for both coaches and triathletes to better structure the training process according to the specificities of the race distance and the individual characteristics of each triathlete.

In this review, we aim to systematically summarize the available literature on the biophysical assessment of a continuous triathlon effort, whether in isolated segments or full race simulations on various race formats.

2. Materials and methods

This systematic review was developed following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 statement [53]. The protocol registration was made in the INPLASY database (registration number INPLASY202510121), which was published on 28 January 2025 (Doi: 10.37766/inplasy2025.1.0121).

2.1. Eligibility criteria

Table 1. Search strategy and inclusion/exclusion criteria based on PICOS.

Search terms	PICOS	Inclusion criteria	Exclusion criteria
Triathlon Events Segments Swim* Cycle* Cycling Run* Athlete Competi* Biomechanics Physiology Kinematics Kinetics Biophysics Effort Perform*	Population	Healthy competitive triathletes aged ≥ 15 years.	Triathletes with clinical conditions aged < 15 years
	Intervention	Biomechanical and/or physiological assessment (i.e., biophysical) Continuous effort (simulating segments or full competition) Human participants	Other domains (e.g., psychology, nutrition) Intermittent effort or transitions or protocol comparison Computer modelling
	Comparison	Triathletes' characteristics Triathlon events Triathlon segments	Other sport specialists (swimmers, cyclists, or runners) Environmental conditions (e.g., water temperatures) Equipment utilization (e.g., trisuit) Different training methods
	Outcome	Energetics, cardiovascular demand, aero/hydrodynamics, and technical profile of triathletes	Other domains or race times
	Study design	Experimental cross-sectional and longitudinal research design	Retrospective or prospective observational studies, randomized control trials

A comprehensive and extensive search of original articles published until 31st December 2024 was done in electronic databases (Web of Science, PubMed, and Scopus). Research articles were included or excluded using the criteria defined by the PICOS strategy (Population, Intervention, Comparison, Outcome, and Study Design) (Table 1). Reviews, overviews, conference abstracts, dissertations, and these were excluded. Articles were included when published in a peer-reviewed journal. No restrictions were applied regarding language, as long as the studies included the title and an abstract written in English. Titles, abstracts, and full articles were screened manually by two independent reviewers, and a single list consolidated the studies that fulfilled the eligibility criteria. During the study selection process, potential biases were assessed based on study design and methodological quality, and duplicate samples were identified through comparison of authors, sample characteristics, and study settings. Any duplicates or studies with a significant risk of bias were excluded to ensure the integrity and reliability of the included data.

2.2. Search strategy

The Boolean search method (including AND/OR) was used to identify the literature containing keywords and terms related to the biophysical profile of triathlon athletes (triathlon, discipline, swim, cycle, run, athlete, biomechanics, physiology, kinematics, kinetics, biophysics, performance). In the three databases (PubMed, Scopus, and Web of Science), the terms had to be presented in the title, abstract, or keywords (using the search by "title/abstract", "title-abstract-key", and "topic", respectively), represented in Table 2.

Table 2. Detailed keyword combinations and search strategies for PubMed, Scopus, and Web of Science databases.

Database	Observations	Adapted query and database fields
Scopus	The search for title and abstract also includes keywords	(TITLE-ABS-KEY("triathlon") AND TITLE-ABS-KEY("biomech*") AND TITLE-ABS-KEY("physiology") AND TITLE-ABS-KEY("kinetics") AND TITLE-ABS-KEY("kinematics") AND TITLE-ABS-KEY("effort") AND TITLE-ABS-KEY("perform*"))
Web of Science	Title/abstract is not available in this database. The option "Topic" includes title, abstract and keywords, and was used instead	"Triathlon" [Title/Abstract] AND ("biomech*" [Title/Abstract] AND "physiology" [Title/Abstract] AND "kinetics" [Title/Abstract] AND "kinematics" [Title/Abstract] AND "effort" [Title/Abstract] AND "perform*" [Title/Abstract])
Pubmed	Nothing to report	Triathlon (Topic) AND Biomech* (Topic) AND Physiology (Topic) AND Kinetics (Topic) AND Kinematics (Topic) AND effort (Topic) AND perform* (Topic)

2.3. Selection process and data extraction

After extraction, the records retrieved from databases were screened independently by two authors, and automated duplicate removal was performed using EndNote 20.6 for Windows (ClarivateTM, Philadelphia, PA, USA). Initially, all data was analyzed by titles and abstracts and then with full-text selection. Records were extracted into a tailored Microsoft® Excel 2016 worksheet (Microsoft Corporation, Redmond, WA, USA) created for data summary. The two authors performed a complete and independent data extraction to group the following physiological or biomechanical outcomes. In case of disagreements, a third author was a mediator, enabling a consensus to be reached. Information was synthesized by: (i) Author(s) and year of publication; (ii) sample characteristics (group, sample size, sex, age); (iii) race format & segment (s) (run, cycle, swim, cycle-run, swim-cycle, full race); (iv) aim; (v) procedures; (vi) major findings; and (vii) quality score.

2.4. Quality assessment

Two authors performed the quality assessment of each study, and doubts were solved by another author (if applicable). The Downs and Black Quality Assessment Checklist [54] was used based on the following criteria: (1) Reporting; (2) external validity; (3) internal validity (bias and confounding); and (4) power. Other systematic reviews reported the use of such tool within the sports domain [55−57]. The original version has 27 items with a maximum score of 32 points. Adaptations were made to the original version, according to the focus of included studies and the modified versions: (i) The term 'patient' was replaced by 'participant', and 'testing' was used instead of 'treatment' [56]; (ii) items 4, 8, 9, 14, 15, 17, 19, and 22–26 were excluded when not applicable to the study design (e.g., cross-sectional study); and (iii) the answer of item 27 was modified to 'yes' (1 point) and 'no' (0 points) than the five options. Methodological quality was classified as (i) low, with a score ≤ 50%; (ii) good, with a score between 51% and 75%; and (iii) excellent, with a score > 75% [58]. The degree of agreement between reviewers (inter-rater reliability) in the scoring procedure was obtained based on Cohen's Kappa coefficient (κ) [59] and interpreted according to Landis and Koch's suggestion [60]: (i) No agreement if $\kappa < 0$; (ii) poor agreement if $0 < \kappa < 0.19$; (iii) fair agreement if $0.20 < \kappa < 0.39$; (iv) moderate agreement if $0.40 < \kappa < 0.59$; (v) substantial agreement if $0.60 < \kappa < 0.79$; and (vi) almost perfect agreement if $0.80 < \kappa < 1.00$.

For a more accurate grouping process, there was a need to define a new categorization model of the different triathlon race formats. While some researchers [5,61−63] used terminology as short-distance (Sprint, Olympic) and long-distance (70.3, Ironman), those did not consider the modernization of the sport by the appearance of the Supertri or T100. To fill this gap, we categorized triathlon formats as (i) short-distance formats; the ones that take less than 1h hour to complete (e.g., Super Sprint, Supertri, Arena Supertri E World Triathlon, and Sprint); (ii) middle-distance formats; those lasting between 1h-5h (e.g., Olympic, T100 and 70.3); and (iii) long-distance formats; races taking efforts longer than 5h (e.g., Ironman).

3. Results

3.1. Study selection

A total of 8560 potentially relevant records were identified from PubMed (*n* = 1452), Scopus (*n* = 3653), and Web of Science (*n* = 3401). From those, 968 duplicates were excluded, leaving 7538 records to be manually screened by title and abstract, and 465 remaining sought for retrieval (removed *n* = 7073). A total of 198 full texts were assessed for eligibility, and 164 of those were excluded due to the PICOS framework's exclusion criteria. In the end, a total of 30 relevant studies were considered for further analysis. In this sense, the included articles were grouped considering their biophysical assessment as short-distance (*n* = 18) and middle-distance (*n* = 12) race formats. No study was included in the long-distance race format category. The complete and detailed search process is shown in Figure 1.

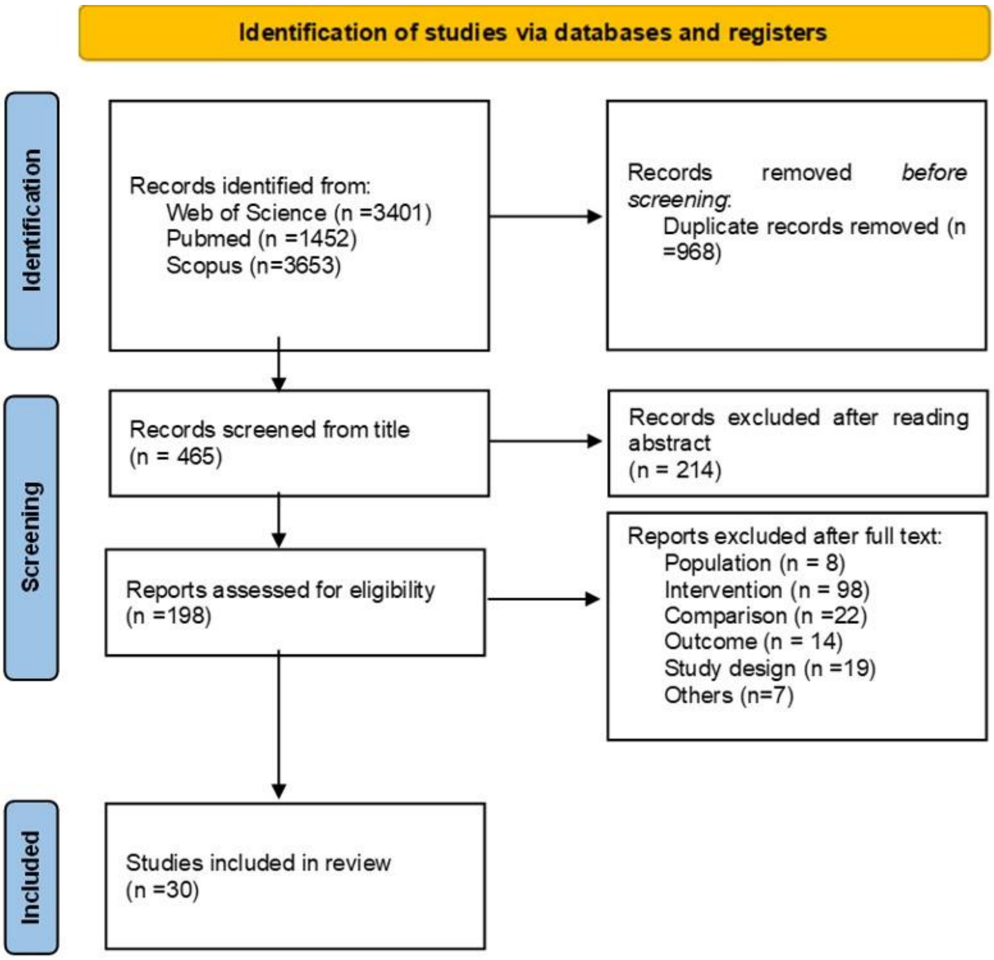

Figure 1. PRISMA 2020 flow chart for studies' identification, screening, and inclusion.

3.2. Quality of included studies

The reliability between both reviewers showed an almost perfect agreement (κ = 0.94) in the scoring procedure using the quality index. All studies were considered for assessment with a maximum of 17 points. A summary of the QI for each study (points and%) is provided in Tables 3 and 4. The overall QI had a mean score of 11.86 ± 1.05 points (range of 10 to 14 points) and a percentage of 70.37 ± 6.16% (range of 58.8% to 82.4%). All studies performed better in reporting items and bias than in external validity, confounding, and power. Items related to the aim and hypothesis description, sample characteristics, estimates of random variability, and the definition of the outcomes to be measured were more clearly defined in most of the included studies.

The 18 studies that entailed short-distance race formats had a mean quality score of 12.00 ± 1.05 points (range of 10 to 14 points) and a mean percentage of 70.60 ± 6.22% (range of 58.8% to 82.4%). The 12 studies that entailed middle-distance race formats had a mean quality score of 11.92 ± 1.04 points (range of 10 to 13 points) and a mean percentage of 70.11 ± 6.12% (range of 58.8% to 76.5%).

3.3. Study characteristics

The characteristics of the included studies are shown in Tables 3 and 4. Concerning the country of publication, 10 studies (33.3%) were from France [14,18,64–69,70,71], 8 (26.7%) from Australia [16,17,72–77], 5 (16.7%) from Spain [15,78–81], 2 (6.7%) from Japan [82,83], 2 (6.7%) from the United States of America [84,85], 1 (3.3%) from Germany [86], 1 (3.3%) from the United Kingdom [87], and 1 (3.3%) from Brazil [88].

The 30 included studies contained data from 412 healthy triathletes, and the athletes' mean ± SD age was 27.0 ± 3.6 years. The selected sample size often ranged from 2–10 (65.6%), 11–20 (31.3%), and > 20 (6.3%) participants. Regarding segments, 2 studies (6.7%) encompassed swimming [78,81], 3 studies (10%) encompassed cycling [14,64,69], 7 studies (23.3%) encompassed running[18,67,68,70,84,86,87], 2 studies (6.7%) encompassed the swim-cycle [79,17], 13 studies (43.3%) encompassed the cycle-run [15,16,65,66,71–77,80,85], and 3 studies (10%) encompassed the full race [82,83,88]. Eighteen studies (60%) encompassed the biophysical assessment of short-distance race formats [14,16,17,64–68,71,73,74,75,77,78,80,84,85,87], and 12 studies (40%) encompassed the biophysical assessment of middle-distance race formats [15,18,69,70,72,76,79,81–83,86,88].

3.3.1. Biophysics of short-distance race formats

A total of 7 of 18 studies accessed Super Sprint [17,67,68,74,80,84,85], while 11 of 18 assessed Sprint distance [14,16,64–66,71,73,75,77,78,87]. Ten studies included recreational triathletes [65–67,71,73,75,78,80,84,87], 5 studies grouped triathletes from several competitive levels [14,16,17,64,85], and 2 studies were with elite triathletes [74,68] (26.5 ± 3.7 years old). This gathers a total of 190 participants, of which 117 were males (61.6%), 28 were females (14.7%), and 45 participants (23.7%) had their sex not identified on sex basis. Regarding segments, 1 study assessed swimming [78], 2 assessed cycling [14,64], 1 assessed swim-cycle [17], 10 assessed cycle-run [16,65,66,71,73–75,77,80,85], and 4 assessed the run [67,68,84,87]. Eight studies entailed physiological variables [14,16,64–66,73,78,87], 7 entailed biomechanical variables [17,67,68,74,80,84,85], and 3 investigated EMG variables [71,77,75].

3.3.2. Biophysics of middle-distance race formats

Of the 12 studies, 10 assessed the Olympic distance [15,18,70,72,76,79,81,83,84,88] and 2 assessed the 70.3 distance [69,86]. A total of 222 participants (28.2 ± 3.1 years old) were recruited being categorized as recreational triathletes in 7 studies [69,70,72,82,83,86,88], national/international triathletes in 1 study [79], and elite triathletes in 4 studies [15,18,76,81]. A total of 160 participants were males (72.1%) and 52 females (23.4%), but 10 participants (4.5%) were not identified according to their sex. Regarding segments, 1 study assessed swimming [81], 1 assessed cycling [69], 3 assessed running [18,70,86], 1 assessed swim-cycle [79], 3 assessed cycle-run [15,72,76] and three studies assessed the full race [82,83,88]. Five studies investigated physiological variables, [72,79,82,83,88], 4 investigated biomechanical variables [15,18,81,86], and 3 investigated electromyography (EMG) variables [69,70,76].

Table 3. Summary of the studies regarding biophysical responses in short-distance race formats (n = 18).

Author/Year	Sample	Race format & Segment(s)	Main aim	Procedures	Major findings	Quality score
(Barragán et al., 2020) [78]	♂n = 7 23.42 ± 3.25 years Recreational	Sprint S	Analyze different swim intensities on overall triathlon performance	3 Sprint triathlons at 3 S intensities (70, 80 and 90%) The peak HR and blood lactate were measured after each segment, and at the end of the complete triathlon	90% S intensity = best triathlon result Swimming intensity is determinant for the final performance of a Sprint distance triathlon	12 (70.6%)
(Suriano & Bishop, 2010) [73]	♂n = 5 ♀n = 3 35 ± 4 years Recreational	Sprint C-R	Determine the effect of cycle intensity on subsequent running performance and combined cycle–run (C-R) performance	Series of C-R tests, at various cycle intensities, followed by an all-out, 5 km run Gas analysis Blood samples	↑VO_2, HR, and La at ↑cycling intensity C-R performance is maximized when the cycle is completed at the highest sustainable intensity	11 (64.7%)
(Hausswirth et al., 2001) [64]	♂n = 10 25.6 ± 4.1 years National	Sprint C	i) Compare the physiological responses during a triathlon where cycling was performed ADT or CDT ii) Study the incidence of these two drafting modalities in cycling on the subsequent running performance done during a simulated triathlon	2 Sprint triathlons (ADT and CDT) Indoor pool and indoor C and R track Breath by breath Gas exchange continuous on C and R Blood samples	↑Velocity, VO_2, VE, HR and La in running at CDT. ↓VO_2, VE, HR, La, and cadence in cycling at CDT CDT enables triathletes to save a significant amount of energy during the cycle of a Sprint triathlon and creates conditions for a ↑run performance compared with ADT	13 (76.5%)

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Author/Year	Sample	Race format & Segment(s)	Main aim	Procedures	Major findings	Quality score
(Hausswirth et al., 1999) [14]	♂ n = 8 20.8 ± 2.1 years National	Sprint C	Compare the responses during a triathlon in which cycling was performed alone vs draft	2 Sprint triathlons (alone *vs*. draft) Breath by breath exchange Blood samples	↑VO_2, VE, and HR on the cycling (alone triathlon) ↓Velocity, VO_2, HR, VE, and La on the run (alone triathlon) Drafting will enable to conserve energy during cycling and improve the run phase	13 (76.5%)
(Taylor & Smith, 2013) [87]	♂n = 8 36.0 ± 5.7 years Recreational	Sprint R	Examine how residual fatigue affects the relationship between ratings of RPE, physiological responses, and pacing during triathlon performance	Repeated measures: -750 m S (pool)-20 km C (road)-5 km R (road) -isolated 5 km R trial Lactate on transitions, core temperature pill and HR	Residual fatigue impairs running performance during triathlon Apparent absence of any RPE 'resetting' between disciplines due to the cognitive pacing strategy	12 (70.6%)
(Vercruyssen et al., 2005) [65]	♂n = 8 28.9 ± 7.4 years Recreational	Sprint C-R	Investigate the effect of cadence selection during the final minutes of cycling on metabolic responses, stride pattern, and subsequent running time to fatigue	30 min C on turbo trainer (FCC, -20%FCC, +20%FCC)-R to fatigue at 85% of Vmax (treadmill) Video analysis Gas exchange Blood sample	↑T_{max} after FCC -20% associated with the ↓ metabolic load during the final of cycling changes in muscular activity probably contribute to the effects of cadence variation on T_{max} in running	12 (70.6%)

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Author/Year	Sample	Race format & Segment(s)	Main aim	Procedures	Major findings	Quality score
(Walsh et al., 2017) [16]	♂n = 8 27.8 ± 6.2 years National and international	Sprint C-R	Investigate and compare the cardiorespiratory and biomechanical responses during the TR in comparison with C-R at moderate intensity using an exercise protocol known to minimize the impact of undue fatigue	10 min CR (treadmill) 1 h rest 20 min C (turbo trainer)-30 min R (treadmill) Gas exchange continuous w/ breath by breath HR 3D motion video analysis	↑f_b, VE, and VE/V_{CO_2} in TR compared to C-R. ↑mean HR in TR ↓mean SL ↑mean SR	13 (76.5%)
(Vercruyssen et al., 2002) [66]	♂n = 8 24.0 ± 3.0 years Recreational	Sprint C-R	i) Investigate the effects of three pedaling cadences on the energy cost of cycling with exercise duration (30 min); ii) Study the influence of these cycling cadences on the energy cost of the subsequent run	-45 min IR (treadmill) at VT_{run} + 5% -3 sessions (3 different cadences EOC, FCC, MOC) 30 min C (ergometer)-15 min R (treadmill) Physiological parameters non-continuous assessment	↑Cycling cadences contribute to an ↑ in energy cost during cycling and the appearance of a VO_2 slow component during subsequent running Cycling at EOC leads to stability in energy cost of locomotion with exercise duration	11 (64.7%)

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Author/Year	Sample	Race format & Segment(s)	Main aim	Procedures	Major findings	Quality score
(Bentley et al., 2007) [17]	♂♀n = 9 25.1 ± 5.8 years Regional to National level	Super Sprint S-C	Investigate the physiological responses and performance during a cycling TT preceded by swimming bouts at different intensities including a trial where a no draft in swimming was allowed	3 x 400 m S at different intensities followed by a 20 min C. Breath by breath gas analysis on C Blood samples Swim kinematics	↓Cycling performance with ($SC_{100\%}$) ↓Mean power output during a cycle TT when prior swimming is performed Drafting/swimming at a lower velocity did not induce any conflicting effects on power output during a subsequent cycle TT	11 (64.7%)
(Candau, et al., 1998) [67]	♂♀n = 15 26.6 ± 3.1 years Recreational	Super Sprint R	Examine the physiological and mechanical factors which may be involved in the increase in energy cost during treadmill running to exhaustion	3 km R on treadmill maximum velocity Gas analyzer breath-by-breath, kinematic arm to measure kinetics	↑VO_2 explained about 25% of the ↑C_R in the fatigued state The external mechanical work could partly explain the ↑ in C_R	10 (58.8%)
(Gottschall & Palmer, 2002) [85]	♂n = 13 24.78 ± 1.20 years College athletes	Super Sprint C-R	Determine if cycling cadence affects subsequent running velocity through changes in stride frequency	3 sessions: -30 min C-3200 m R (track) (20% slower cadence, control cadence and 20% faster cadence) Video recording for kinematic analysis	↑Cycling cadence, ↑SF, and ↑run velocity	11 (64.7%)

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Author/Year	Sample	Race format & Segment(s)	Main aim	Procedures	Major findings	Quality score
(Olcina et al., 2019) [80]	♂n = 8 ♀n = 2 25.7 ± 8.9 years Recreational	Super Sprint C-R	Analyze the effect of previous cycling on subsequent running performance in a field test, while using kinematics metrics and SmO_2 provided by wearable devices that are potentially used by triathletes	IRT (Cooper test on track) BRT (20 min ergometer c-C-C-R (cooper test on track) Kinematics- HR strap SmO_2- Second by second on VL using NIRS	Intense cycling prior to running in triathletes may impair running performance due to a ↓SL and the inability to peripherally utilize oxygen in muscles (↑% SmO_2)	13 (76.5%)
(Rabita et al., 2011) [68]	♂n = 6 23.2 ± 3.2 years ♀n = 3 25.0 ± 4.4 years Elite	Super Sprint/ Sprint R	i) Evaluate changes in leg-spring behavior during an exhaustive run, in elite triathletes ii) Determine whether these modifications were related to an increase in the energy cost of running (C_r)	Constant velocity run performed until exhaustion corresponding to 95% of vVO_{2max} Force platform system Oxygen uptake breath by breath	Runners with greatest ↑energy cost of running were those with greatest changes in stiffness	12 (70.6%)
(Rendos et al., 2013) [84]	♂n = 13 ♀n = 16 24.6 ± 5.8 years Recreational	Super Sprint R	Compare sagittal plane running kinematics after a 30 min cycling protocol to a baseline run without prior exercise	1x5 repeated measures: 30 min C (turbo trainer)-15 min R (treadmill) Kinematics- video analysis Kinetics- GRF from treadmill	↑Peak hip flexion angles ↑Anteriorly rotated pelvis ↑Spine extension during the stance phase ↓Hip extension Less triathlon experience = more kinematic changes in TR	11 (64.7%)

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Author/Year	Sample	Race format & Segment(s)	Main aim	Procedures	Major findings	Quality score
(Walsh et al., 2023) [74]	♂n = 5 ♀n = 4 24.3 ± 7.6 years National level and/or World Triathlon level	Super Sprint C-R	Characterize alterations of lower limb intersegmental coordination during the acute phase of running after cycling among highly trained triathletes using an analysis of planar covariation	10 min CR (treadmill) 60 min rest 20 min C (turbo trainer)-10 min R (treadmill) 3D video analysis Gas exchange breath by breath	Cycling at a moderate intensity with variable-cadence has a significant effect on run loop planarity and therefore intersegmental coordination in highly trained triathletes Alterations to lower limb coordination are corrected during the run	13 (76.5%)
(Le Meur et al., 2012) [71]	♂n = 10 30 ± 6.0 years Recreational	Sprint C-R	Evaluate spring–mass (SM) behavior and associated EMG activity during a run to exhaustion following a cycle exercise in trained triathletes	30 min C (ergometer)-R (treadmill) to fatigue at LT Two contact-sensing resistors- spring mass EMG 9 lower limb muscles Gas analyzer continuous measures Blood samples	↑EMG activity during the pre-contact phase for VM and RF at T-$Run_{5\%}$ ↓EMG RMS during the pre-contact phase for VM, VL, RF, and SOL from T-$Run_{60\%}$, and during the braking phase for SOL and GaM at T-$Run_{80\%}$	13 (76.5%)

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Author/Year	Sample	Race format & Segment(s)	Main aim	Procedures	Major findings	Quality score
(Walsh et al., 2015) [77]	♂♀n = 6 24.8 ± 7.6 years Australian National level and/or ITU level	Sprint C-R	Examine changes to EMG patterns of the lower limb at physiologically determined times during the cycle-run transition period to better investigate neuromuscular adaptations	10 min IR (treadmill) 30 min rest 20 min C (turbo trainer)-30 min R (treadmill) EMG 8 lower limb muscles Breath-by-breath oxygen consumption	Moderate intensity prior to cycling had a minimal impact on MRA and HR values during the C-R Variability of MRA does appear to increase during C-R when compared to IR. MRA and VO_2 during the C-R do not share any meaningful link	14 (82.4%)
(Bonacci et al., 2010) [75]	♂♀n = 15 26.9 + 4.4 years Recreational	Sprint C-R	Examine the direct effect of cycling on running muscle activity and movement patterns in moderately trained triathletes	10 min CR (treadmill) 45 min rest 15 min C (turbo trainer)-30 min R (treadmill) EMG 11 muscles on lower limbs 3d motion video analysis	Some triathletes have difficulty reproducing their pre-cycling movement patterns for running, but cycling appears to have little influence on running muscle recruitment in moderately trained triathletes	11 (64.7%)

Notes 1- S-Swim; C- cycle; R-run; S-C-R- swim to cycle to run; MAS- maximal aerobic speed; HR- heart rate; VO_2- oxygen consumption; $VO_{2\,max}$ maximum oxygen consumption; VE- ventilation; La- lactate concentration; AD- alternated draft; CD- continuous draft; RPE- perceived rating of exertion; S-C- Swim-cycle; C-R- Cycle to run; EOC- energetically optimal cadence; FCC- freely chosen cadence; MOC- mechanical optimal cadence; CR- control run; TR- transition run; IR- isolated run; ADT- Alternated draft triathlon; CDT- Continuous draft triathlon; VT- ventilatory threshold; V_E/Vco_2 - Ventilatory efficiency; MRA- muscle recruitment activity; RMS- root mean square; T-$Run_{5\%}$- run to exhaustion; VM- vastus medialis; VL- vastus lateralis; RF- rectus femoris; SOL- ; GaM-, gastrocnemius medialis; soleus; FCC- freely chosen cadence; rpm- revolutions per minute; GL- gastrocnemius lateralis; GRF- Ground reaction forces; vVO_{2max}- velocity at VO_{2max}; CR- control run; TR- transition run; TT-time trial; IRT- isolated run trial; BRT- bike to run trial; SmO_2- muscle oxygenation; SL- stride length; NIRS- near-infrared spectroscopy; C_R- energy cost of running; T_{max}-running time to fatigue; f_b -respiratory frequency; VT_{run}- ventilatory threshold on the run; and LT- lactate threshold.

Table 4. Summary of studies regarding biophysical responses in middle-distance race formats (n = 12).

Author/Year	Sample	Race Format & Segment(s)	Main aim	Procedures	Major findings	Quality Index
(Lopes et al., 2012) [88]	♂n = 12 27.9 ± 1.73 years Recreational	Olympic S-C-R	Investigate the behavior of physiological variables before the event and after each segment of an Olympic Triathlon	1500 m S (pool)-40 km C-10 km R (outdoor) Blood samples HR measure	↑HR ↑La in cycling followed by swimming then running	13 (76.5%)
(Miura et al., 1997) [82]	♂n = 17 26.5 ± 8.2 Recreational	Olympic S-C-R	Determine the relationship between Olympic distance triathlon and economy determined by% VO_2max during a simulated laboratory test triathlon.	Continuous 1,5 km S (flume pool), 40 km C (ergometer), 10 km R (treadmill) S-C-R at 60% intensity Automatic gas-collection systems every 60 sec	Significant correlation between the index of economy determined by% $VO_{2\ max}$ at cycling and running segments during a simulated laboratory test ↑VO_2 ↑VE ↑HR during the protocol	11 (64.7%)
(C. Du Plessis et al., 2020) [72]	♂n = 17 34 ± 6 years Recreational	Olympic C-R	The influence of a simulated cycling bout on running physiological cost	Two treadmill running bouts before and after a high intensity cycling bout Breath by breath gas exchange	Overall detrimental impact of a high intensity cycling bout on subsequent running economy	13 (76.5%)

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Author/Year	Sample	Race Format & Segment(s)	Main aim	Procedures	Major findings	Quality Index
(González-Haro et al., 2005) [79]	♂n = 4 International ♂n = 2 National 25.3 ± 4.2 years	Olympic S-C	Cardiorespiratory and metabolic adaptation (at race pace) during Olympic distance triathlon	1500 m S-1 h C La (S and C) Breath by breath gas exchange (C)	↑La in swimming ↓La at the end of swimming compared to the end of cycling ↑MAS swim	12 (70.6%)
(Fraeulin et al., 2021) [86]	♂n = 16 32.1 ± 6.0 years Recreational ironman triathletes	70.3 R	Compare the starts of a WR and a TR by means of statistical parametric mapping (SPM) applied to full step cycles	First 20 steps of a run after a warm-up run (WR) and TR following a 90 min cycling session were analyzed with video and Xsense system	In TR: ↑trunk extension, hip flexion in the flight phase ↑Knee extension in the initial swing ↑Flexion in the terminal swing Prior cycling induces difficulties in finding one's preferred running pattern especially in the beginning of the run	12 (70.6%)
(Miura et al., 1999) [83]	♂n = 8 faster 27.3 ± 6.8 years ♂n = 8 slower 26.0 ± 10.3 years All recreational	Olympic S-C-R	Investigate the respiratory and circulatory features during simulated lab triathlon and compare differences between slower and faster triathletes	Continuous 1.5 km S (pool)-40 km C (ergometer)-10 km R (treadmill) S-C-R at 60% of $VO_{2\ max.}$ Continuous gas exchange every 60 sec	Faster triathletes ↓increments in VO_2, VE, HR, and T_E Slower triathletes ↓VO_2 and ↑O_2 cost↑VO_2 max in cycling and running Progressive ↑VE ↑T_E during the race	11 (64.7%)

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Author/Year	Sample	Race Format & Segment(s)	Main aim	Procedures	Major findings	Quality Index
(Cala et al., 2009) [15]	♂n = 10 ♀n = 10 Elite	Olympic C-R	Determine effects of prior 40 km C to 10 km R during a World Cup triathlon competition	Video recording at C-R and in each 2.5 km run lap to analyze kinematics	Prior cycling does not impair subsequent run, in elite triathletes: ↓Run efficiency only at the last lap due to ↓velocity and ↓SL No differences between men and women in run technical profile	11 (64.7%)
(López-Belmonte et al., 2023) [81]	♂n = 10 ♀n = 4 23.36 ± 3.76 years Elite	Olympic S	(i) Analyze the 1500 m open water swimming performance; (ii) Examine the associations between physiological and biomechanical variables with swimming performance; (iii) Determine which variables can predict swimming performance in triathletes	1500 m open water test Oxygen uptake was continuously measured, during 5 min before (baseline) and after the test in a sitting position, breath by breath HR Video analysis	Positive associations were found between EE˙VO_2 and swimming velocity and SI with swimming performance Negative associations between oxygen uptake and buoy-turn times were negatively associated with performance SI main predictor of open water performance	13 (76.5%)
(Hausswirth et al., 2000) [70]	♂n = 7 31 ± 5 years Recreational	Olympic R	Compare the EMG signal of the vastus lateralis muscle obtained during the run segment of triathlon and at the end of a prolonged run performed at the same running velocity	30 min S (pool)-60 min C (road)-45 min R (treadmill) Prolonged run (1 h 30 min road-45 min treadmill)	2 h 15 min prolonged run induced ↑neuromuscular alterations, identified by an integrated EMG flow of the VL muscle, then a triathlon lasting the same amount of time	11 (64.7%)

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Author/Year	Sample	Race Format & Segment(s)	Main aim	Procedures	Major findings	Quality Index
(Le Meur et al., 2013) [18]	♂n = 43 ♀n = 36 Elite	Olympic R	Analyze the behavior of the step temporal parameters and spring-mass variables during the run segment of an international Olympic distance triathlon in order to identify the effects of fatigue on running mechanics	Video recording in World Triathlon Grand Final 2011 Each triathlete was filmed 5 times in the run segment Kinematics: Kinovea Kinetics: race-time curve during contact	↓Velocity, vertical stiffness, and leg stiffness during the 4 laps Overall spring-mass regulation was not altered over the run in elite competitors SL explained, to a greater extent than SF, the running velocity variance in elite triathletes	10 (58.8%)
(Heiden & Burnett, 2003) [76]	♂♀n = 10 29.2 years Elite	Olympic C-R	Determine the effect of prior cycling on EMG activity of selected lower leg muscles during running	2 tests: -40 km C (turbo trainer) to 2 km R (treadmill) -10 km R to 2 km R (treadmill) EMG on 6 lower limb muscles Single directional accelerometer for kinematics	Difference in the duration of VL activation across sections of the 2 km run Changes in muscle function when changing from cycling to running	13 (76.5%)

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Author/Year	Sample	Race Format & Segment(s)	Main aim	Procedures	Major findings	Quality Index
(Argentin et al., 2006) [69]	♂n = 8 26.1 ± 4.0 years Recreational	70.3 C	Determine whether the integrated EMG signal of two lower limb muscles indicates preferred cadence during a 2 h cycling task	2 h laboratory cycle at 65% of maximal aerobic power The integrated EMG signal of the VL is and GL muscles was recorded during MVC and the cycle task	↓FCC from P1 to P2 ↓MVC on VL and GL Muscle activation at constant power was not minimized at specific cadences Only the GL muscle was affected by a 2 h cycling task, whereas VL remained stable.	13 (76.5%)

Notes 2- S-Swim; C- cycle; R-run; S-C-R- swim to cycle to run; MAS- maximal aerobic speed; HR- heart rate; VO_2- oxygen consumption; $VO_{2\,max}$ maximum oxygen consumption; VE- ventilation; La- lactate concentration; RPE- perceived rating of exertion; S-C- Swim-cycle; C-R- Cycle to run; CR- control run; TR- transition run; IR- isolated run; VT- ventilatory threshold; $\dot{V}_E/\dot{V}co_2$ - Ventilatory efficiency; T_E- temperature of external auditory canal; MVC- maximum voluntary contraction; SI- swim index; WR- warm-up run; TR-transition run; P1- period 1 (start of the cycling test); and P2- period 2 (end of the cycling test).

4. Discussion

Our aim of this study was to synthesize the evidence regarding biophysical responses of a continuous triathlon effort, whether in isolated segments or full race simulations. This study was designed to help coaches and triathletes better understand how energetic and biomechanical variables influence performance. While it is consensual that endurance and technical aspects are key issues for the outcome in a triathlon race, the way coaches can manage the training load specifically for each race format is an unsolved topic. In this sense, understanding the biophysical responses derived from each race format could give coaches new insights into how to prepare training sessions and better specialize athletes accordingly.

4.1. Quality assessment

Although there were interesting insights into the included studies with great practical implications for the field, the quality scores remained quite low (11.86 out of 17). Interestingly, the mean quality score of short-distance studies is similar to studies focused on middle-distance formats. Some critical aspects were not adequately addressed, like the sample choice (e.g., inclusion and exclusion criteria definition). None of the studies used complex sample procedures, such as randomization, blindness, the use of a control group, and/or practical effects. Since recruiting elite triathletes is not an easy task, most researchers take the chance to recruit based on convenience samples. Furthermore, none of those studies reported whether any participants were lost during the protocols, which would indicate the capacity for them to remain tested in a very demanding sport. Researchers should be aware and careful with the confounding and power factors, as only a few articles scored in this category. Moreover, the sample power is also an issue, since none of the articles calculated a prior sample size.

4.2. Biophysics of the short-distance race formats (super sprint and sprint)

In Super Sprint, the distance of the swim segment is 400 m, corresponding to approximately 3% of the total race distance [89] and accounting for 18.22% and 18.17% of the total race time for male and female triathletes, respectively [90]. It is expected that the intensity of the swimming effort and draft effects influenced posterior cycling [50,91]. Swimming at maximum effort without drafting results in a reduction in mean power output during cycling, due to higher lactate concentration in the blood (~7 mmol/L) [17]. Contrarily, swimming at 90% max effort in the same conditions produced less lactate 4 mmol/L and caused a subsequent higher cycling cadence and an initial higher power output [17]. The improvement of this initial swimming segment can even be more potentiated if there is a chance to benefit from draft effects [39,50]. So, the best swimming strategy seems to be swimming at sub-maximal effort and looking for drafting benefits, which can also be dependent on how accustomed the triathlete is to draft strategy.

The following cycling segment covers about 77.5% of the whole race distance [92] and accounts for 49.36% and 49.90% of the total race time for male and female triathletes, respectively [90]. Cycling in this format requires the triathletes to maintain a high pace on technically difficult courses, showing repetitive, high-intensity accelerations, high power, and velocity [93]. Since a higher number of groups is formed, contrary to longer distance race formats, the positioning strategy could determine the final race result [89]. There is a need to generate higher power output in short periods at the beginning of the segment, to overtake other triathletes, which requires a higher aerobic power and more anaerobic contribution development to match the effort [94]. Although cycling has a higher correlation with overall race performance, the position at the beginning of the run segment can indicate the final classification in a race.

The running distance covers about 19% of the overall race and accounts for 26.13% and 26.16% of the total race time for male and female triathletes, respectively [90], which makes this a segment that is difficult for changes in placement, even if triathletes are remarkably close to each other [92]. The running segment is expected to be influenced by the previous cycling segment. Elite triathletes have an altered intersegmental coordination of the lower limbs before running, which is rapidly corrected during the sixtieth minute of the run segment [74]. Higher velocity (e.g., 16−18 km/h) results in amplified changes in lower limb coordination [74,95,96], indicating that triathletes should train the transition from cycling to running at the same velocity as in the competition to obtain some kind of a modulation effect of neural networks, enabling them to save energy [97,98]. When maintaining velocities at 95% velocity of VO2max (vVO2max), leg-spring stiffness decreases, leading to a higher energy cost in elite triathletes [68].

This is of particular importance for recreational triathletes, as running pattern is altered after cycling with higher peak hip flexion angles, a more anteriorly rotated pelvis, and a greater spine extension during the stance phase [84]. The less experience the triathlete is, the greater the kinematic changes are, making the triathlete more susceptible to injuries [84], which requires additional attention from coaches for this skill-specific phenomenon. As outlined, this is unlikely to make changes in placement on the running segment. Probably, it may be more advantageous to adopt a pacing strategy that may involve initiating the run at a maximal intensity and sustaining it for as long as physiologically tolerable to either maintain or move up in the position until the finishing line [94].

In the Sprint race format, the swim segment seems to cover only 2% of the total race distance and accounts for 16.47% and 16.06% of the total race time for male and female triathletes, respectively [90]. Swimming at a higher intensity (~90% of maximum velocity) improves the overall race time and cycling performance but slightly decreases run performance in the case of recreational triathletes [78]. In elite triathletes, swimming at a lower intensity (~70% of maximum velocity) enables the athlete to cycle and run faster, leading to a better race performance [99]. In this type of race format, a steadier swimming effort (with RPE values of 14−15) seems to be more advantageous for the subsequent segments throughout the race [87].

Here, the cycling segment also accounts for 77.5% of the whole race distance [92], like in Super Sprint, but accounts for 52.81% and 52.37% of the total race time for male and female triathletes, respectively [90]. The best strategy seems to cycle at the sustainable intensity ~81−90% of the lactate threshold [73]. Cycling at a higher intensity (higher power outputs) may increase VO2max, HR, and lactate and seems to negatively affect the subsequent run segment, especially in the first kilometer [73]. In addition, physiological fatigue caused by cycling at higher intensities may also lead to more neuromuscular and potentially psychological fatigue [100]. Triathletes should find a balance between generating sufficient power to perform well during the cycling segment and conserving enough energy for the subsequent run. A poor cycling performance cannot be compensated during the run segment [73]. Cycling at lower cadences (-20% than freely chosen cadence- FCC) results in lower lactate production (2.7 mmol/L), lower HR (142bpm), and lower oxygen consumption (VO2) (48.6 ml/kg/min) at the end of the cycling segment, which is expected to benefit running performance due to less energy cost. Higher cadences (FCC and FCC+ 20%) lead to higher lactate production (3.2−4.7 mmol/L), higher HR (150−152 bpm), and higher VO2 (50.1−51.2 ml/kg/min) at the end of the cycling segment, resulting in a higher energy cost, negatively affecting the run [65]. In this sense, the choice for high cycling cadences (mechanical optimal cadence and freely chosen cadence) contribute to the appearance of VO2max slow component during subsequent running, which leads to a recruitment of more type II muscle fibers that causes increase in lactate production and ventilation, making the run less economical [66]. Most economical cadences performed at an intensity 5% above ventilatory threshold are beneficial in terms of VO2 and lead to a reduction in energy cost during cycling with positive benefits in the subsequent run segment [66].

Like in the Super Sprint race format, in Sprint there are strategic aspects like drafting in both the cycle and run segments that can also influence the overall race positioning. A global reduction is expected in VO2 (−14%), HR (−7.5%), and VE (−30.8%) for the drafted cycling segment and time for the 5 km run [14]. While the continuous draft reduces VO2max, HR, lactate, pedaling rate, and run time compared to alternate draft, the cycling velocity seems to remain unchanged in both conditions. This means that cycling in a continuous draft enables the triathlete to save energy by facilitating the run [64]. The cycling segment is the longest and any effort management regarding power, cadence, and drafting should be a priority in training in order to maximize cycling performance without compromising the run.

Around 19.4% of the Sprint race format distance is taken up by the run segment and accounts for 28.28% and 29.15% of the total race time for male and female triathletes, respectively [90]. The way triathletes approach the run segment after transition from the cycling segment may differ according to their competitive level. Recreational triathletes who cycle at a sub-maximum intensity have not altered muscle recruitment but have altered running kinematics, taking almost five minutes for them to correct their running pattern [71]. This fact can come from a high leg stiffness and the need to change muscle recruitment, increasing EMG activity in vastus lateralis [71]. On the contrary, elite triathletes are capable of correcting their running pattern instantaneously [75], which could be explained by the adaptations already gained during a more demanding transition-specific training [77].

Despite the substantial body of research on short-distance race formats, a gap remains in the literature concerning the precise characterization of the predominant bioenergetic zones across these events, as well as their respective physiological and mechanical implications. Addressing this gap is essential for advancing both performance optimization and evidence-based training prescription. Therefore, a detailed biophysical analysis format by format is required to have a deeper understanding of the specific demands of each short race in order to trigger the best result.

4.3. Biophysics of the middle-distance race formats (olympic and 70.3)

In middle-distance, the swim segment seems to cover 2.9% and 1.7% of the overall race distance in Olympic and 70.3 race formats, respectively [90]. In the Olympic race format, it accounts for 16.85% and 16.33% of the total race time for male and female triathletes, respectively [90], and in the 70.3 race format, it accounts for around 11% of the total race time for both male and female triathletes [101]. Regarding similar percentages on the distance, the contribution of the segment in each race format is different. For instance, in the Olympic race format, the drafting effect in the cycling segment is allowed, which can lead to a more energy-saving strategy [102]. Within this, a higher velocity could be achieved when compared to 70.3 race format, as slow swim may result in a slower cycling group or a lonely cycling segment [101]. However, the pacing strategy is the same in both formats, i.e., a without significant variations in velocity [103].

The initial part of the swim segment of an Olympic race format seems to be fastest, as triathletes aim to achieve a strategic position [104]. For instance, stroke rate, stroke length, and stroke index values are the highest in the first 250 m when compared to the remaining distance [81]. In fact, it seems that a better swimming technique helps to find a balance between a fast start, which enables triathletes to get a strategic position. An efficient technique is crucial to maintain swimming velocity and save energy in open water conditions, which is essential for the subsequent cycling and running segments [81]. However, the open water conditions play a key role in the swimming technique and, therefore, in performance [81]. Stroke index and velocity do not seem to follow a linear trend during the 1500 m, as swimmers need to modify their stroke depending on tides, waves, and currents [105]. Therefore, triathletes should focus their training on technique as the stroke index is positively associated with swimming performance [13]. However, coaches should be aware that sex may affect swimming biomechanics, as females had fewer changes in biomechanical variables than males [81].

Enhancing swimming technique requires an understanding of the specific muscles involved [106]. The latissimus dorsi and the triceps brachii are the muscles that contribute most to propulsion [107,108], whereas lower limb muscles only contribute ~15% to the overall propulsion [107]. In fact, the longer the distance, the smaller their contribution to propulsion will be, as they become more used for buoyancy purposes [109]. This may explain why triathletes (especially in long-distance race formats) experience dizziness during the transition from swimming to cycling, as they shift from a horizontal to a vertical position, which leads to a rapid redistribution of blood flow from the torso (upper body muscles are more activated) to the legs [63,110]. Some strategies to avoid dizziness in this transition include adopting a higher frequency kick at the end of the swim, to facilitate the redistribution of blood flow to the legs or adopting quadrupedal locomotion and slowly transitioning to a vertical position [51].

Regardless of the race format, drafting during the swim is allowed and could benefit the triathlete [39,111]. Drafting behind another triathlete induces less muscle activation in latissimus dorsi, triceps brachii, and rectus femuris [109], less muscle fatigue, and more energy stored for the following segments [111,112]. Although stabilizer muscles, such as the rectus abdominis, have lower levels of activation when compared to latissimus dorsi and the triceps brachii, requiring a sub-maximal effort [113], those are crucial during the entire race [114,115]. Thus, triathletes should include core training in their training program to improve performance in all segments and avoid technical imperfections and potential injuries.

Once the swimming technique is optimized, training intensity emerges as a critical determinant of performance. Swimming at maximal aerobic speed (MAS) (1.29 m/s) induces lactate values in the end of the segment of 6.6 mmol/L and an HR of 162 bpm, and caused a subsequent cycling done at a lower intensity (77% of MAS), which enables the triathletes to maintain a constant effort in the cycling segment [79]. Despite this, the behavior of physiological variables tends to differ between different competitive levels. Recreational triathletes that swim at 1.07 m/s have lower lactate concentrations after the effort (5.7 mmol/L), but have the same HR value as elite triathletes (~162 bpm), showing that these athletes are less aerobically conditioned [88]. Regarding VO2 during the swim, the VO2max values were higher in faster triathletes (61.5 ml/kg/min) when compared to slower triathletes (54.3 ml/kg/min) [83]. The behavior of VO2 also differed between different level triathletes. In faster triathletes the VO2 rose until reaching the VO2max value and then stabilized, while in slower triathletes the VO2 did not stabilize, it rose until the end of the swim reaching the VO2max value [83].

More experienced triathletes reached their sustainable VO2max earlier and were able to maintain it, indicating better aerobic potency and efficiency. To enhance performance in the swimming segment it is required to improve technique and to increase lactate threshold and VO2max. These adaptations not only lead to faster swim times but also promote a more efficient transition to the cycling segment.

In the cycling segment, the mean value of lactate concentrations is ~7 mmol/L derived from the previous swimming effort [88]. The mean values of VO2max during cycling without previous swimming seem to range from 45.5 ml/kg/min [72] to 61.1−67.8 ml/kg/min for faster triathletes, and 54.9 ml/kg/min for slower triathletes [83], demonstrating that both physical condition and prior swimming are key aspects to be considered. Despite this, the behavior of VO2 seems to be dependent on the competitive level as faster triathletes showed a tendency to decrease their values in the beginning of the cycling segment and then stabilize, contrary to slower triathletes that tend to show an increase over the segment [82,83].

Despite the drafting in cycling, both formats also seem to differ how triathletes position themselves on the bike [93]. While in the 70.3 race format, the cycling segment covers 79.6% of the total race distance and accounts for around 55% and 56% of the total race time for male and female triathletes, respectively [101], requiring prolonged, submaximal steady-state efforts and management of energy consumption [92], the Olympic format cycling covers 77.6% of the total distance [90], and cycling accounts for 52.25% and 52.14% of the total race time for male and female triathletes, respectively [90]. The 70.3 race format is characterized as having a non-technical cycling race course [92], most triathletes adopt an aerodynamic position on the bike to reach higher velocity and save energy [116]. In contrast, in the Olympic format, courses are more technical and require repetitive high-intensity accelerations, as well as higher power/velocity [92]. Regardless of the differences between race formats, triathletes perform conservatively in cycling due to the running segment that follows [93,117]. Thus, they tend to be cycling fast enough only to keep sight of the leaders, while conserving enough energy for a competitive run [118,119]. Moreover, the cycling segment is a strategic phase to eat and hydrate after the swimming segment to enable a final boost in the run segment [101].

As in the cycling segment, the running pacing strategies in both formats are similar [103]. The running distance covers 18.6% of the total distance of a 70.3 race and 19.4% in the Olympic race format. This segment has also a different contribution for the total race time in both formats [90,101]. In the Olympic race format, the run segment accounts for around 29−30% of the total race time for both male and female triathletes [90,101], and in the 70.3 race format, it accounts for around 33 to 35% of the total race time in both male and female triathletes. The longer the run, the greater the tendency for the pace decreases [119]. This means running velocity is more difficult to sustain in a 70.3 than in the Olympic format. Although race formats share similarities, the interaction between segments varies significantly [103].

In the run segment, the lactate mean value is 4.47 mmol/L indicating a tendency of lactate removal which is accompanied by a HR decrease after the cycling segment [88]. However, this is not a clear phenomenon since HR increases from cycling to running (run: 191 bpm vs. cycling: 161 bpm) have been observed in other studies [72,82]. These mixed findings could be explained by the different testing environments. Running on a laboratory treadmill induced higher HR in running than cycling [72,82] while running in an outdoor environment showed lower run HR values [88]. In relation to VO2max, it had the same behavior as HR even in slower triathletes, and similar to other segments, the mean value was lower in slower triathletes 59.3 ml/kg/min, and the values were increasing during the run compared to 69.7 8 ml/kg/min mean value and a tendency for stabilization during the run in faster triathletes [83].

Increases in VO2max during the cycle and the run could be explained by dehydration and an increase in HR due to cardiovascular drift [83]. Faster triathletes have small increments of VO2 max and HR and have a better thermoregulation than less aerobically conditioned triathletes, causing easier workload and VO2 during the run, which means that training plays an important role in the overall race performance [83]. Faster triathletes have higher VO2max values, which have an association with the index of economy (% VO2max at the last minute of each segment) during the cycle and run segments, suggesting that this variable could determine overall race time [82]. Thus, coaches should work on the triathletes' VO2 max [82].

In other endurance sports (e.g., marathon and half marathon) VO2 max is not a determining variable unlike lactate threshold [120], but in cycling, VO2 max could determine success. For instance, in the Tour de France and Vuelta a España, cyclists showed a contribution of approximately 7−23% between 71.2−100% of $\dot{V}$O2 max of the total intensity [121]. Since triathlon involves both cycling and running, and due to the nature of cycling dynamics (drafting, chases) in some race formats (short distance and Olympic), VO2 max could be an important physiological variable. It is hypothesized that in longer distances (70.3 and full ironman), VO2 max becomes less important and that lactate threshold will play a key role.

In elite triathletes, prior cycling does not appear to influence run efficiency [15,18], but at the end of the run, a decrease in efficiency due to accumulated fatigue can be observed [15]. However, sex interplays in this behavior, as differences between men and women were well documented for run kinematics and kinetics [15]. Women tend to maintain a better technique compared to men, which enables them to sustain a more consistent velocity. These smaller fluctuations in velocity make women more efficient [15]. Variables such as stride length and horizontal distance hip-heel may be influenced by stature, with stride length explaining running velocity variance to a greater extent than step frequency in elite triathletes [18]. Triathletes with shorter stride lengths relative to their height may exhibit better running economy than those with longer stride lengths relative to their height [122]. Since there is an inverse relationship between stride length and stride frequency, it is recommended that triathletes engage in running technique training aimed at increasing stride frequency [122]. On the other hand, angular kinematic variables can be affected by differences in strength and flexibility between men and women [15]. Similar to kinematic variables, kinetic variables, such as spring-mass variables (vertical stiffness and leg stiffness), do not change during the 10 km run. The kinetic variables had the same behavior as velocity during the race. In a middle-distance triathlon (e.g., 70.3), the run technique tends to deteriorate because of the aerodynamic cycling position [84]. This cycling position is characterized by the static stretching of the back extensor muscles and extreme hip flexion, and the cyclic concentric movement of pedaling induces performance-specific fatigue in muscles [84]. When transitioning to the run, spinal extensor muscles need to adapt, inducing a pronounced trunk extension, increased hip flexion in the flight phase, more knee extension in the initial swing, and increased flexion in the terminal swing [84]. In 70.3 race format prior cycling induces difficulties in finding one's preferred running pattern [86].

In Olympic and 70.3 race formats, there are more differences in running EMG activity than cycling [69]. According to the chosen cadence in cycling, no differences were found in EMG activity of the vastus lateralis regardless of the chosen cadence; however, there is a greater level of EMG in the gastrocnemius in higher cadences (90 and 110 rpm) [69]. Additionally, freely chosen cadence tends to decrease at the end of long cycling tasks due to changes in muscle fiber recruiting pattern [69]. Thus, higher cycling cadences may be harmful for the subsequent run, since it induces fatigue in the gastrocnemius, a muscle required (higher activation) in running mechanics [123]. In the run segment, there is an increase in the level of activation in the biceps femuris and vastus lateralis on the stance phase and an increase in the duration of activation in the vastus medialis and biceps femuris on the flight phase [76].

Thus, isolated prolonged running induces high neuromuscular alterations, identified by an increase in the integrated EMG flow of the vastus lateralis muscle, in contrast to a transition run [70]. The cycle to run transition induces less muscle fatigue, suggesting that brick training is not as injury prone as running alone [124,125]. To avoid injuries, particularly triathletes who race in middle-distance race formats and require higher volumes of training, they should be careful with the volume of running and probably will benefit more from brick training (more repetitions of shorter runs intercalated with cycling) than with long runs.

Triathlon is a relatively recent sport that has gained increasing attention in competitive and scientific contexts. Although some researchers have examined the physiological and/or biomechanical responses in certain triathlon events, they are limited to short- and middle-distance formats and often exhibit low methodological quality. There is a lack of research on long-distance events and emerging formats such as T100, Supertri and Arena Supertri. While assessing the full long-distance triathlon events brings practical challenges, future research could encompass a comprehensive evaluation of the biophysical demands of each segment, providing valuable insights for training and performance optimization.

5. Conclusions

It can be concluded that the biophysical profile of triathletes in the various race formats is influenced by multiple factors, including competitive level, segment-specific demands, and sex. As a sport that integrates three different segments, triathlon is inherently complex, requiring an integrated approach of physiological and biomechanical responses to ensure smoother effort and transitions between segments to enhance the overall performance. The literature shows a low-quality score and is restricted to short or medium distance race formats. Researchers should be more precise in how they design their studies and try to clarify literature gaps by studying longer-distance events (e.g., Ironman and Deca-Ironman), as well as new emerging race formats (e.g., Supertri, Arena Supertri E World Triathlon Championship, or T100).

Use of generative-AI tools declaration

The authors declare they have not used Artificial Intelligence (AI) tools in the creation of this article.

Conflict of interest

The authors declare no conflict of interest.

Author contributions

MM, CCS and MJC conceived and planned the study. MM and L A-C performed the systematic search, data extraction and quality analysis. CCS and MJC performed the interpretation of the results. MM, CCS and MJC wrote and critically reviewed the manuscript. All authors approved the final version of the manuscript.

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