

Intermittent vs. continuous tests for monitoring swimming performance: A systematic review with meta-analysis

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Abstract

Approach: Intermittent incremental tests (ITT), intermittent tests (IT), and continuous tests (CT) provide physiological parameters along with the corresponding swimming speeds (v), which are valuable for decision-making by coaches. **Purpose:** This study aimed to summarise and compare the effectiveness of ITT, IT, and CT in monitoring physiological parameters – oxygen uptake (VO_2), the blood lactate concentration ($[\text{La}^-]$), and heart rate (HR) – as well as their associated v . **Methods:** The PubMed, EMBASE, and Web of Science databases were searched for complete studies published in English, from 1 January 2000 to 24 January 2024. Eleven studies ($n = 164$ swimmers) fulfilled the inclusion criteria. A meta-analysis was performed. **Results:** The results of the studies were homogeneous ($p > 0.05$) when v was also similar between the tests: ITT compared with CT (7 studies, $n = 88$ swimmers) VO_2 $0.03 \pm 0.15 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{minute}^{-1}$, $I^2 = 0\%$, $p = 0.99$; v $0.08 \pm 0.14 \text{ m} \cdot \text{s}^{-1}$, $I^2 = 0\%$, $p = 0.89$; IT compared with CT (3 studies, $n = 44$ swimmers) $[\text{La}^-]$ $0.12 \pm 0.21 \text{ mmol} \cdot \text{L}^{-1}$, $I^2 = 0\%$, $p = 0.64$; HR $-0.32 \pm 0.2 \text{ beats} \cdot \text{minute}^{-1}$, $I^2 = 0\%$, $p = 0.37$; v $0.08 \pm 0.14 \text{ m} \cdot \text{s}^{-1}$, $I^2 = 0.00\%$, $p = 0.89$). **Conclusions:** The VO_2 results for the comparisons between IT and CT, and the $[\text{La}^-]$ and HR results for comparisons between IT and CT were similar when: (i) the v was also similar between the tests, and (ii) the duration of the tests was long enough to obtain more stable physiological data.

Keywords: Evaluation, Protocols, Physiological, Kinematic, Swimming Speed

Introduction

Performance assessments in swimming provide details regarding the best training process to achieve the best competitive results (Amara et al., 2022; Morais et al., 2022). Part of these evaluations aims to obtain physiological and biomechanical performance parameters based on intermittent incremental, intermittent, and continuous tests for monitoring swimming (Almeida et al., 2022; Barbosa et al., 2015; de Jesus et al., 2012; de Souza et al., 2016; Di Michele et al., 2012; Feitosa et al., 2020; Zacca et al., 2019). Of note, there has been little research that systematically gathers information on comparisons between intermittent incremental and continuous tests, an area that would be useful for coaches and swimmers.

Intermittent incremental tests provide the swimmer's energy and technical profile through a series of steps with an increase in intensity and a short interval between sets (Zacca et al., 2019). There are intermittent tests with no increase in intensity with each new set, but with intervals between the steps (Almeida et al., 2022). On the other hand, there are also continuous tests, with no predetermined breaks during the effort – for example, fixed distance or time trials – which are used to assess aerobic power and its associated speed, among other variables such as the stroke length and the stroke rate (Arsoniadis et al., 2020; Thompson & Cooper, 2002; Zacca et al., 2016). Continuous tests, the 200- or 400-m, 30-minute test, compared with intermittent incremental tests (a set of series by distances, e.g., $5 \times 200 \text{ m}$ or 300 m , $7 \times 200 \text{ m}$, or simply $N \times 200 \text{ m}$), sometimes seem more friendly to coaches and swimmers due to the time savings (the shorter the test, the better the time savings), the lower work rate, and the less intense physiological responses (Billat et al., 1996; Cardoso et al., 2002; de Jesus et al., 2015; Fernandes et al., 2003; Lomax et al., 2018).

Swimming must be grounded in the context of scientific evidence. Thus, for a real phenomenon to exist, there must be evidence of its presence (Rushall, 2009). The validity of the measure is its ability to demonstrate the degree to which the scores of the protocol or instrument measure what it intends to measure (Thomas et al., 2008). Decision-making when choosing the most appropriate test for monitoring performance can be based on information from valid, reliable, and accurate replicated data. However, the choice of a test (e.g., intermittent incremental, intermittent, and/or continuous tests) suitable for monitoring physiological performance parameters in swimming requires summarised knowledge of the characteristics of each test and its associated speed, as well as the test's duration (Hill et al., 2002; Pelarigo et al., 2018). A preliminary search of the PubMed, EMBASE, and Web of Science databases returned 2,807 articles on tests for monitoring physiological performance parameters in swimming. In this context, some studies have been dedicated to investigating

physiological performance parameters obtained in tests: intermittent incremental versus continuous tests (Zacca et al., 2019); intermittent versus continuous tests (Nikitakis et al., 2019); and comparisons between intermittent incremental, intermittent, and continuous tests (Almeida et al., 2022). These tests for monitoring physiological performance parameters should not be expensive, should be relatively simple, should not be time-consuming, and should provide real-time results via accurate and solid evaluations.

The focus of this systematic review and meta-analysis is on studies with swimmers who took part in intermittent incremental swimming, intermittent, and continuous tests to monitor physiological parameters, namely oxygen uptake (VO_2), the blood lactate concentration $[\text{La}^-]$, the heart rate (HR), and the swimming speed (v), corresponding to the tests. VO_2 , $[\text{La}^-]$, HR, and the v associated with the tests were compared among the includes studies to determine whether the results are similar for intermittent incremental versus continuous tests (Almeida et al., 2022; Arsoniadis et al., 2020; Campos et al., 2017; Cardoso et al., 2002; Espada et al., 2021; Feitosa et al., 2020; Pelarigo et al., 2018; Zacca et al., 2019), and intermittent versus continuous tests (Almeida et al., 2022; Greco et al., 2010; Nikitakis et al., 2019). Although there are a reasonable number of studies that have compared these tests, there is no summary of these data together in the literature. The duration of each test is fundamental to achieve more trustworthy physiological results, for example, peak oxygen uptake ($\text{VO}_{2\text{peak}}$) in tests lasting > 2 minutes (Hill et al., 2002). These test results can provide useful information for prescribing training intensities in situations such as at the $[\text{La}^-]$ threshold speeds, at anaerobic thresholds, at the speed of maximum aerobic power, and avoiding interrupting the protocol due to reaching high levels of fatigue and consequent impairment of movement quality (Cardoso et al., 2002; Zacca et al., 2019). Therefore, the aim was to systematically summarise studies with comparisons between intermittent incremental, intermittent, and continuous tests to monitor physiological parameters (VO_2 , $[\text{La}^-]$, and HR) and the corresponding v .

Methods

This systematic review was carried out following the recommendations of the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) statement (Page et al., 2021).

Eligibility criteria

The eligibility criteria were based on the inclusion of studies recruiting young and adult swimmers, with the aim of carrying out a systematic review of studies comparing intermittent incremental, intermittent, and continuous tests to monitor swimming performance. The following were considered eligible for this review: tests that assess swimming performance; tests carried out in scientific research with young and adult swimmers with or without impairment; tests that address at least one of the four conventional swimming strokes in tests to collect physiological data (VO_2 , $[\text{La}^-]$, and HR) with the corresponding v ; and tests that address possible levels of accuracy, correlation, association, heterogeneity, agreement, with competitive tests. Studies in English, with the full text available, and published from January 2000 to January 2024 were considered to fulfil the eligibility criteria. The exclusion criteria were: studies with computer-based modelling of swimmers' physical parameters; lack of information and/or incomplete data in the articles, abstracts, editorials, and comments; and multiple publications in which the results were repeated – only one of these studies was included.

Databases and search strategy

The PubMed, EMBASE, and Web of Science databases were searched for studies published between 1 January 2000 and 24 January 2024. The reference lists of the included articles were also searched. The search strategy included Medical Subject Headings (MeSH) terms and Health Science Descriptors (DeCS) as well as their synonyms and combinations of words for the following categories in English: **Population** – swimmer, swimmers, swimming, swim; **Intervention** – “time trial test”, “maximum test”, “continuous test”, incremental, “incremental test”, intermittent, “intermittent incremental”, “intermittent trials”, “intermittent exercise testing”, 100-m, “100 m”, 200-m, “200 m”, 400-m, “400 m”, 800-m, “800 m”, 1500-m, “1500 m”, Medley, “100-m front-crawl test”, “100 m front crawl test”, “200-m front-crawl test”, “200 m front crawl test”, “400-m front-crawl test”, “400 m front crawl test”, “800-m front-crawl test”, “800 m front crawl test”, “1500-m front-crawl test”, “1500 m front crawl test”; **outcome** – aerobic, anaerobic, “blood lactate concentration”, “heart rate”, “oxygen consumption”, “uptake oxygen”, “peak oxygen uptake”, biomechanics, kinematics, “swimming speed”, “stroke length”, “stroke rate”, “speed variation”, “intra-cyclic velocity variation”, “speed fluctuation”. The Boolean operators “AND” and “OR” were used for tracing when searching the electronic databases.

Selection of studies and extraction of results

The studies were selected in two stages. For the first stage, the titles and abstracts of all the articles identified from the searches were read by two researchers, who worked independently. The studies that did not provide sufficient detail regarding the inclusion and exclusion criteria were selected for full article assessment. For the second stage, the same reviewers independently assessed the full content of the articles and decided whether the article should be included according to the eligibility criteria. Disagreements between the two reviewers were resolved by a third independent reviewer. Data were extracted by using a standardised form.

Outcomes

The outcomes of this study involved the protocols used in scientific research to monitor the performance of swimmers with or without impairment. Intermittent incremental, intermittent, and continuous

tests were explored according to the inclusion of physiological parameters and the v associated with the test. The test duration was also investigated.

The physiological parameters included VO_2 absolute ($\text{L}\cdot\text{min}^{-1}$) and VO_2 relative ($\text{mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$), which were obtained from studies that used any form of respiratory gas collection by a gas analyser or metabolic card (de Jesus et al., 2014). The peak $[\text{La}^-]$ was determined based on venous blood collected from the earlobe or fingertip; it is presented as the highest value reached after the effort of the swimming tests (Sousa et al., 2010). HR in $\text{beats}\cdot\text{minute}^{-1}$ is presented in absolute values.

The biomechanical parameters included (i) the clean v , which does not consider the times of exits, turns, and arrivals (Daly et al., 1999); (ii) the stroke rate, the number of strokes per unit of time; and (iii) the stroke length, the average distance travelled by the body in each stroke cycle (Craig & Pendergast, 1979; Hay & Guimarães, 1983).

Assessing the risk of bias

The Downs and Black Quality Assessment Checklist was used to score the overall quality of the studies (Downs & Black, 1998). Higher scores represent higher quality articles. The scores are expressed as a percentage (Correia et al., 2023; Feitosa et al., 2019), calculated as $[(\text{total number of points obtained}/\text{total number of points applicable}) \times 100]$. Two reviewers independently used this score to assess the risk of bias. In case of disagreement for some items on the checklist, a third reviewer was asked to reconcile the different opinions.

Data analysis

Quantitative analysis was carried out on the main characteristics of the studies, with information on the publication, the sample, and the main protocols and their specificities. To facilitate the process of analysing the studies according to the eligibility criteria, the data from the articles were organised in Excel 2019 spreadsheets (Microsoft, Redmond, WA, USA) according to the intervention characteristics of each study and the inclusion and exclusion criteria. The meta-analysis was performed using a random-effects model (Borenstein et al., 2010). The inconsistency test (I^2) assessed the statistical heterogeneity among the studies, in which the values represent heterogeneities. It was interpreted as null, close to 0%; low, close to 25%; moderate, close to 50%; and high, close to 75% (Borenstein et al., 2009). The alpha was set at 0.05. For the risk of bias analysis, a forest plot was generated in the Comprehensive Meta-Analysis software (Version 2.2.064, USA).

Results

The search strategy identified 2,807 articles, of which 1,278 were duplicates; only one study was included from other sources, found in the article references (Figure 1). In the first phase, 1,514 studies were excluded after analysing the titles and abstracts. In the second phase, four studies were excluded after reading the full text. In total, 11 articles ($n = 164$ swimmers) were extensively examined because they met the established inclusion criteria (Figure 1, Table 1).

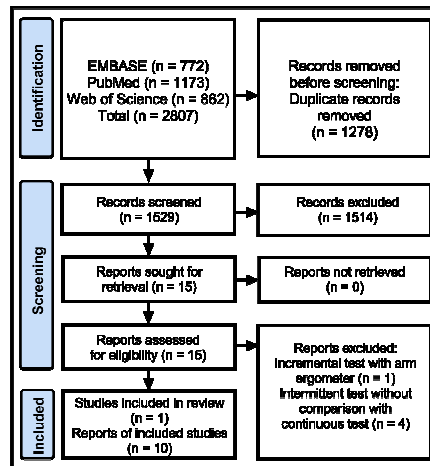


Figure 1. Flowchart of the systematic literature search.

Table 1 summarises the studies that compared intermittent incremental, intermittent, and continuous tests. The intermittent incremental tests ($n = 9$ studies) were mostly developed in the $N \times 200\text{-m}$ model, with slight variations in the number of sets (e.g., $5 \times 200\text{ m}$, $6 \times 200\text{ m}$, and $7 \times 200\text{ m}$) in which the swimmers reached maximum aerobic velocity (MAV) or the lowest velocity at which $\text{VO}_{2\text{max}}$ was elicited, namely $v\text{VO}_{2\text{max}}$ (Almeida et al., 2022; Arsoniadis et al., 2020; Campos et al., 2017; Cardoso et al., 2002; Espada et al., 2021; Feitosa et al., 2020; Pelarigo et al., 2018; Thompson & Cooper, 2002; Zacca et al., 2019).

Table 1 also summarises the studies that compared intermittent incremental tests with continuous tests ($n = 9$ studies), and intermittent tests with continuous tests ($n = 3$ studies). One of the comparisons was among the three types of tests analysed (intermittent incremental, intermittent, and continuous tests). The quality of the included studies included ranged from 53.85% to 73.08, with a mean $\pm$ standard deviation of $65.73\% \pm 5.56\%$ (Table 1).

It was possible to see that the v between the tests was similar, regardless of the parameter analysed, for example, in intermittent incremental and continuous tests when comparing $\text{VO}_{2\text{peak}}$ or $\text{VO}_{2\text{max}}$ (Almeida et al., 2022; Campos et al., 2017; Cardoso et al., 2002; Feitosa et al., 2020; Zacca et al., 2019); VO_2 at the anaerobic threshold speed (IaT), ventilatory threshold speed (VT), and heart rate threshold speed (HRT) (Pelarigo et al., 2018); or even the lactate threshold speed (sLT) of both tests (Arsoniadis et al., 2020). In addition, v was similar in the three studies that compared physiological and kinematic parameters in intermittent and continuous tests (Almeida et al., 2022; Greco et al., 2010; Nikitakis et al., 2019).

Author, year	Quality Score %	Participants/Competitive level	Test	Oxygen uptake ($\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ or $\text{L} \cdot \text{min}^{-1}$)	Blood lactate concentrations [La^-] ($\text{mmol} \cdot \text{L}^{-1}$)	Heart Rate HR ($\text{beats} \cdot \text{min}^{-1}$)	Kinematic parameter
Cardoso et al. (2002)	57.69	Male $n = 05$ and Female $n = 06$, recreational swimmers, water polo players and triathletes	IIT 7 $\times$ 200-m, 30 s interval vs. CT 30 min. Both tests started at $0.9 \text{ m} \cdot \text{s}^{-1}$ with increments of $0.05 \text{ m} \cdot \text{s}^{-1}$ for each 200-m step	$\text{VO}_{2\text{peak}}$ ($\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$) IIT 53.4 ± 8.74 ; CT 52.5 ± 9.44	IIT 8.86 ± 1.93 ; CT 7.36 ± 1.31	IIT 187.5 ± 8.44 ; CT 183.1 ± 9.47	IIT $v\text{VO}_{2\text{max}}$ $1.15 \pm 0.09 \text{ m} \cdot \text{s}^{-1}$; CT $v\text{VO}_{2\text{max}}$ $1.16 \pm 0.09 \text{ m} \cdot \text{s}^{-1}$
Thompson & Cooper (2002)	46.15	Male $n = 15$ /National, breaststroke swimmers	IIT 5 $\times$ 200-m, 30 s interval vs. CT 100-m (competition finishing times)		Swimming speed at [La^-] First test 2 $\text{mmol} \cdot \text{L}^{-1}$, $r = -0.76$; $r^2 = 53.90$; 4 $\text{mmol} \cdot \text{L}^{-1}$, $r = -0.73$; $r^2 = 49.80$; 6 $\text{mmol} \cdot \text{L}^{-1}$, $r = -0.79$; $r^2 = 58.70$ Second test 2 $\text{mmol} \cdot \text{L}^{-1}$, $r = -0.60$; $r^2 = 28.6$; 4 $\text{mmol} \cdot \text{L}^{-1}$, $r = -0.65$; $r^2 = 35.9$; 6 $\text{mmol} \cdot \text{L}^{-1}$, $r = -0.70$; $r^2 = 41.8$	Swimming speed at % of maximum HR First test $r = -0.68$; $r^2 = 41.50$	First test Stroke Rate at $1.3 \text{ m} \cdot \text{s}^{-1}$, $r = 0.63$; $r^2 = 34.60$
Thompson & Cooper (2002)	46.15	Male $n = 15$ /National, breaststroke swimmers	IIT 5 $\times$ 200-m, 30 s interval vs. CT 200-m (competition finishing times)		Swimming speed at [La^-] First test 2 $\text{mmol} \cdot \text{L}^{-1}$, $r = -0.76$; $r^2 = 54.80$; 4 $\text{mmol} \cdot \text{L}^{-1}$, $r = -0.63$; $r^2 = 36.10$; 6 $\text{mmol} \cdot \text{L}^{-1}$, $r = -0.72$; $r^2 = 47.20$ Second test 2 $\text{mmol} \cdot \text{L}^{-1}$, $r = -0.64$; $r^2 = 33.80$; 4 $\text{mmol} \cdot \text{L}^{-1}$, $r = -0.75$; $r^2 = 51.90$; 6 $\text{mmol} \cdot \text{L}^{-1}$, $r = -0.82$; $r^2 = 63.90$	Swimming speed at % of maximum HR First test $r = -0.77$; $r^2 = 56.10$	First test Stroke Rate at $1.3 \text{ m} \cdot \text{s}^{-1}$, $r = 0.55$; $r^2 = 25.10$
Greco et al. (2010)	57.69	Male $n = 12$ /Regional and National	CT MLSS T30 (%Velocity of 400-m test – V400, and 2.5% increases and reduction in speed) vs. IT MLSS (12 $\times$ 150 s, interval 30 s)		CT 3.4 ± 1.00 ; IT 3.9 ± 1.20 %V400 91.3 ± 2.6	CT 172.7 ± 6.10 ; IT 170.8 ± 7.40	CT V400 $1.38 \pm 0.05 \text{ m} \cdot \text{s}^{-1}$, MLSS T30 Speed $1.23 \pm 0.05 \text{ m} \cdot \text{s}^{-1}$; IT %V400 89.3 ± 2.0 ; MLSS Speed $1.26 \pm 0.05 \text{ m} \cdot \text{s}^{-1}$
Campos et al. (2017)	57.69	Male $n = 6$ and Female $n = 3$	IIT 6 $\times$ 200-m, 30 s interval vs. CT 400-m	$\text{VO}_{2\text{peak}}$ ($\text{L} \cdot \text{min}^{-1}$) IIT 4.09 ± 0.93 ; CT 3.86 ± 0.85			IIT Velocity $1.39 \pm 0.12 \text{ m} \cdot \text{s}^{-1}$; CT Velocity $1.34 \pm 0.13 \text{ m} \cdot \text{s}^{-1}$

Pelarigo et al. (2018)	53.85	Female n = 10, elite swimmers	<i>IIT</i> 7×200-m, 30 s interval (lanT, VT, HRT, LT _{3.5}) vs. <i>CT</i> MLSSc (2 or 3 of 30 min submaximal constant swimming tests)	VO ₂ (mL.kg ⁻¹ .min ⁻¹) <i>IIT</i> VO _{2max} 54.9 ± 6.7; lanT 45.9 ± 5.1; VT 45.1 ± 5.3; HRT 45.9 ± 4.5; LT _{3.5} 52.3 ± 6.3; <i>CT</i> 46.4 ± 4.9	<i>IIT</i> lanT 1.49 ± 0.41; VT 1.55 ± 0.54; HRT 1.81 ± 0.71; LT _{3.5} 3.5 ± 0.00 <i>CT</i> 1.90 ± 0.77	<i>IIT</i> lanT 172.3 ± 7.5; VT 170.1 ± 8.3; HRT 172.1 ± 8.0; LT _{3.5} 185.1 ± 9.1 <i>CT</i> 173.6 ± 9.7	<i>IIT</i> Velocity: lanT 1.24 ± 0.06 m·s ⁻¹ , VT 1.23 ± 0.05 m·s ⁻¹ , HRT 1.24 ± 0.06 m·s ⁻¹ , LT _{3.5} 1.32 ± 0.06 m·s ⁻¹ <i>CT</i> Velocity: 1.24 ± 0.07
Zacca et al. (2019)	61.54	Male n = 6 and Female n = 5/National	<i>IIT</i> 7×200-m, 30 s interval vs. <i>CT</i> 400-m	VO ₂ (mL.kg ⁻¹ .min ⁻¹) <i>IIT</i> 54.6 ± 4.70; <i>CT</i> 54.4 ± 6.60	<i>IIT</i> 6.2 ± 1.5; <i>CT</i> 6.5 ± 1.9	<i>IIT</i> 187 ± 10; <i>CT</i> 184 ± 9	<i>IIT</i> vVO _{2max} 1.32 ± 0.05 m·s ⁻¹ ; Stroke Length 2.3 ± 0.2 m; Stroke Rate 36.1 ± 2.5 cycles·min ⁻¹ ; <i>CT</i> Velocity 1.29 ± 0.07 m·s ⁻¹ ; Stroke Length 2.1 ± 0.2 m; Rate 35.7 ± 1.7 cycles·min ⁻¹
Nikitakis et al. (2019)	53.85	Children Male n = 10 and adolescents male n = 10	<i>IT</i> 10 × 200-m at a Critical Speed (35–45 s interval) vs. <i>CT</i> T30 (MLSS – two to four continuous 30 min swimming efforts at a constant submaximal speed)	VO ₂ (mL.kg ⁻¹ .min ⁻¹) <i>IT</i> Children: ~ 41.80 ± 2.83, Adolescents: ~ 46.66 ± 1.04; <i>CT</i> Children: 40.7 ± 7.4, Adolescents: 46.3 ± 6.6 ml·kg ⁻¹ .min ⁻¹	<i>IT</i> Children 3.8 ± 1.6; Adolescents 3.0 ± 1.1; <i>CT</i> Children 3.5 ± 1.5; Adolescents 3.0 ± 0.7	<i>IT</i> Children 183 ± 2; Adolescents 173 ± 3.00; <i>CT</i> Children 187 ± 8; Adolescents 179 ± 9.00	<i>IT</i> Children: Velocity 1.09 ± 0.06, Adolescents: Velocity 1.32 ± 0.06 m·s ⁻¹ ; <i>CT</i> Children: Velocity 1.08 ± 0.06, Adolescents: Velocity 1.29 ± 0.05 m·s ⁻¹
Arsoniadis et al. (2020)	65.38	Male n = 10 and Female n = 4/regional and national	<i>IIT</i> 7×200-m, 30 s interval vs. <i>CT</i> T30 (a constant speed corresponding to speed at lactate threshold)	VO ₂ (mL.kg ⁻¹ .min ⁻¹) <i>IIT</i> sLT: 42.80 ± 6.20; <i>CT</i> 41.70 ± 6.80	<i>IIT</i> [La ⁻] – sLT 3.4 ± 0.80; <i>CT</i> [La ⁻] – T30 4.7 ± 2.30	<i>IIT</i> HR – sLT 161 ± 10.00; <i>CT</i> HR – T30 173 ± 8.00	<i>IIT</i> sLT 1.31 ± 0.07 m·s ⁻¹ ; Stroke Length 2.6 ± 0.40 m·cycles ⁻¹ ; Stroke Rate 29.7 ± 4.1 cycles·min ⁻¹ ; <i>CT</i> sLT – T30 1.31 ± 0.08 m·s ⁻¹ ; Stroke Length 2.3 ± 0.30 m·cycles ⁻¹ ; Stroke Rate 33.8 ± 2.9 cycles·min ⁻¹
Feitosa et al. (2020)	61.54	Male n = 7 and Female n = 4, SPI/regional and International	<i>IIT</i> N×200-m, 30 s interval vs. <i>CT</i> 200-m	VO ₂ (mL.kg ⁻¹ .min ⁻¹) <i>IIT</i> 38.26 ± 8.34; <i>CT</i> 39.50 ± 8.38		<i>IIT</i> 167.00 ± 14.30; <i>CT</i> 164.73 ± 22.97	<i>IIT</i> vVO _{2max} 0.93 ± 0.16 m·s ⁻¹ ; <i>CT</i> Velocity 0.99 ± 0.19 m·s ⁻¹
Espada et al. (2021)	57.69	Male n = 14 National	<i>IIT</i> 7×200-m, 30 s interval vs. <i>CT</i> T30 (MLSS – two continuous 30 min swimming efforts at a constant submaximal speed, 90 e 95% da V400)		<i>IIT</i> 85% T200 4.83 ± 0.94; <i>CT</i> 4.84 ± 1.53	<i>IIT</i> 85% T200 169.5 ± 6.20; <i>CT</i> 174.2 ± 7.0	<i>IIT</i> Vmax 1.53 ± 0.07 m·s ⁻¹ ; 85% T200 – Stroke Rate 33.88 ± 3.89 cycles·min ⁻¹ ; Stroke Length 2.50 ± 0.32 m·cycle ⁻¹ ; <i>CT</i> V400 1.51 ± 0.07 m·s ⁻¹ ; MLSS _{velocity} 1.36 ± 0.06 m·s ⁻¹ ; Velocity _{4mmol·L⁻¹} 1.36 ± 0.07 m·s ⁻¹ ; Stroke Rate 32.76 ± 4.07

							cycles·min ⁻¹ ; Stroke Length 2.54 ± 0.33 m·cycle ⁻¹
Almeida et al. (2022)	65.38	Male n = 13 and Female n = 9/ National	<i>IIT</i> 6 × 250-m, plus one set of 200-m at maximal intensity, 30 s interval vs. <i>CT</i> Time-limit sessions at MAV until exhaustion (constant load set) vs. <i>IT</i> interval set composed of 100-m, 15 s interval	VO _{2peak} (ml·kg ⁻¹ ·min ⁻¹) <i>IIT</i> Group, 55.2 ± 5.6, Male 57.0 ± 5.7, Female 52.5 ± 4.2; <i>CT</i> Group, VO _{2peak} 55.4 ± 5.1; <i>IT</i> Group 53.1 ± 5.3	<i>IIT</i> Group 8.4 ± 3.3, Male 8.8 ± 3.6, Female 7.9 ± 2.5; <i>CT</i> Group 7.8 ± 2.7; <i>IT</i> Group 7.8 ± 2.8	<i>IIT</i> Group 184.1 ± 9.4, Male 180.4 ± 7.8, Female 188.7 ± 9.2; <i>CT</i> Group 183.2 ± 7.4; <i>IT</i> Group 182.2 ± 10.4	<i>IIT</i> MAV (m·s ⁻¹) or vVO _{2max} Group 1.26 ± 0.09 m·s ⁻¹ , Male 1.30 ± 0.07 m·s ⁻¹ , Female 1.20 ± 0.07; <i>CT</i> and <i>IT</i> (time-limit sessions at MAV until exhaustion)

IIT = Intermittent incremental test; *IT* = Intermittent test; *CT* = Continuous test; SPI = swimmers with physical impairment; *r* = Pearson's product moment correlation; *r*² = coefficient of determination; T30 = 30-minute continuous test; sLT = speed at lactate threshold; Vmax = swimming velocity performed in the last repetition of the incremental step test; V400 = Maximal aerobic velocity; MLSS = Maximal Lactate Steady State; MAV = Maximal aerobic velocity; Velocity_{4mmol·L⁻¹} = swimming velocity eliciting a lactate concentration of 4 mmol·L⁻¹; MLSS_{velocity} = swimming velocity associated to maximal lactate steady state; IAnT = anaerobic; threshold; VT = ventilatory threshold; HRT = heart rate threshold (HRT); LT_{3.5} = lactate threshold fixed in 3.5 mmol·L⁻¹

Meta-analysis of the observational studies

A total of seven studies (n = 88 swimmers of both sexes) were included in the meta-analysis because they pooled comparisons between the intermittent incremental and continuous tests of VO₂ expressions, for example, VO₂ at IAnT, VO_{2peak}, and VO_{2max} (Figure 2A). Despite the differences in the protocols in these studies (e.g., comparisons of intermittent incremental tests of N × 200 m with continuous tests [one study with 200 m, two studies with 400 m, three studies with 30-min test (T30), and a study with a time limit session), the VO₂ results were similar when the v adopted between the tests was also similar (Figure 2D).

The meta-analysis for the VO₂ comparisons resulted in a point estimate (standard difference in the mean) ± standard error of 0.03 ± 0.15 ml·kg⁻¹·minute⁻¹, variance of 0.02 (95% confidence interval [CI] -0.27 to 0.37), Z = 0.20, p = 0.84; I² = 0.00%, p = 0.99 (Figure 2A). Comparisons between the intermittent incremental and continuous tests regarding v (n = 8 studies) resulted in a point estimate ± standard error of 0.08 ± 0.14 m·s⁻¹, variance of 0.02 (95% CI -0.20 to 0.35), Z = 0.55, p = 0.58; I² = 0.00%, p = 0.89 (Figure 2D).

Comparisons between the intermittent incremental and continuous tests regarding the [La⁻] results (n = 82 swimmers of both sexes) showed moderate heterogeneity (I² close to 50%), with a point estimate ± standard error of -0.07 ± 0.23 mmol·L⁻¹, variance of 0.05 (95% CI -0.53 to 0.38), Z = -0.37, p = 0.75; I² = 52.07%, p = 0.06 (Figure 2B).

Similarly, comparisons between the intermittent incremental and continuous tests for the HR results (n = 93 swimmers of both sexes) also showed moderate heterogeneity (I² close to 50%), with a point estimate ± standard error of -0.16 ± 0.23 beats·minute⁻¹, variance of 0.06 (95% CI -0.62 to 0.30), Z = -0.70, p = 0.49; I² = 58.21%, p = 0.03 (Figure 2C).

It was not possible to compare VO₂ between the intermittent and continuous tests. The [La⁻], HR, and v results of the intermittent and continuous tests were also compared (n = 3 studies, n = 44 swimmers of both sexes; Figure 3). In these cases, the [La⁻] (Figure 3A) and HR (Figure 3B) results were similar when the v (Figure 3C) adopted between the tests was also similar. Comparisons between the intermittent and continuous tests for the [La⁻] results showed null heterogeneity (I² close to 0%), with a point estimate ± standard error of 0.12 ± 0.21 mmol·L⁻¹, variance of 0.05 (95% CI -0.30 to 0.54), Z = 0.57, p = 0.57; I² = 0%, p = 0.64 (Figure 3A).

Similarly, comparisons between the intermittent and continuous tests for the HR results also showed null heterogeneity (I² close to 0%), with a point estimate ± standard error of -0.32 ± 0.2 beats·minute⁻¹, variance of 0.07 (95% CI -0.75 to 0.10), Z = -1.50, p = 0.13; I² = 0%, p = 0.37 (Figure 3B). Finally, comparisons between the intermittent and continuous tests for the v resulted in a point estimate ± standard error of 0.28 ± 0.22 m·s⁻¹, variance of 0.05 (95% CI -0.14 to 0.70), Z = 1.31, p = 0.19; I² = 0%, p = 0.41 (Figure 2D).

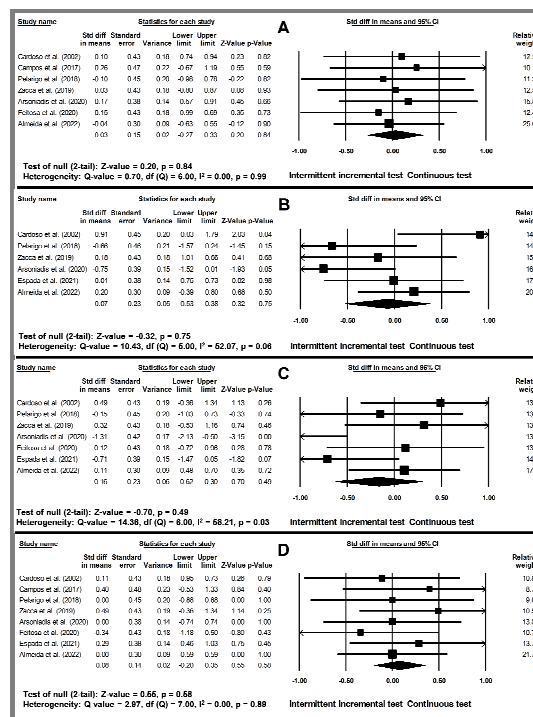


Figure 2. Forest plot derived from continuous random-effects models representing oxygen uptake (letter A), blood lactate concentrations (letter B), heart rate (letter C) and swimming speed (letter D) achieved in intermittent incremental and continuous tests.

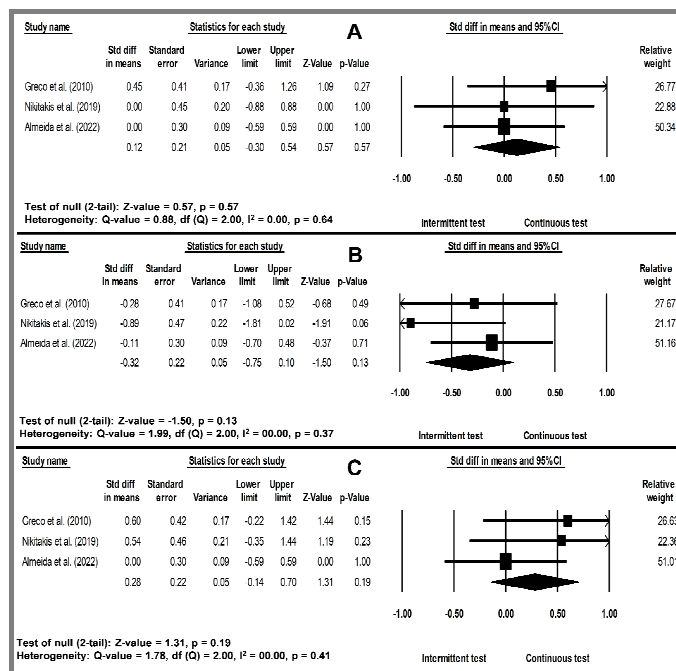


Figure 3. Forest plot derived from continuous random-effects models representing blood lactate concentrations (letter A), heart rate (letter B) and swimming speed (letter C) achieved in intermittent and continuous tests.

Discussion

This review aimed to systematically summarise studies with comparisons between intermittent incremental, intermittent, and continuous tests to monitor physiological parameters (VO_2 , $[\text{La}^-]$, and HR) and the corresponding v. The main findings of the meta-analysis were: (i) the VO_2 results were similar for the intermittent incremental and continuous tests when they also had a similar v and when the duration was >2 minutes; (ii) the $[\text{La}^-]$ and HR results differed between the studies that compared the intermittent incremental

and continuous tests; and (iii) the $[La^-]$ and HR results were similar for the intermittent and continuous tests when they had a similar v and when the duration of the intermittent tests was similar to or longer than the duration for the continuous tests.

The quality of the studies (Downs & Black, 1998) assessed in this investigation (mean $\pm$ standard deviation of $65.73\% \pm 5.56\%$) was similar to a previous study involving swimmers with impairments (mean $\pm$ standard deviation of $64.32\% \pm 11.56\%$; Feitosa et al., 2019), and higher than a study involving swimmers without impairments (mean $\pm$ standard deviation of $45\% \pm 7.85\%$; Correia et al., 2023). In research outside of sports science (e.g., health sciences, biomechanics, and performance), there were slightly higher values compared with the current investigation (Ferreira et al., 2016; Hebert-Losier et al., 2014; Mills et al., 2013). Among the main factors that explain such differences are: (i) randomisation of the intervention groups; (ii) the representativeness of the participants in the population from which they were recruited; (iii) random intervention assignment of participants; and (iv) the list of factors relating to adverse events that may be a result of the intervention (Downs & Black, 1998). However, the results presented in the selected articles are useful for swimming coaches to make decisions, and could be improved in future research.

Oxygen uptake

Some studies have shown that intermittent incremental tests, even with short rest intervals, have made it possible to assess physiological and kinematic parameters with results similar to those obtained in continuous tests (Arsoniadis et al., 2020; Feitosa et al., 2020; Zacca et al., 2019). It is noteworthy that physiological parameters such as VO_{2max} or VO_{2peak} , and vVO_{2max} or even vVO_{2peak} are very important when prescribing the training intensity (Cardoso et al., 2002; Feitosa et al., 2020; Zacca et al., 2019). The similarities, high associations, and close levels of agreement between the pairs of physiological and kinematic results measured for the intermittent incremental and continuous tests seem to respond to requirements such as: (i) the duration of the exercise must not be too short (e.g. <2 minutes), because a short duration would not allow enough time to reach VO_{2max} ; and (ii) the intensity of swimming must be in the severe intensity domain, at which VO_{2max} occurs (Hill et al., 2002). In the domain of severe intensity, VO_{2max} has been established according to primary (the occurrence of a VO_2 plateau with a variation $<2.1 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{minute}^{-1}$, despite an increased v), and secondary criteria (an elevated $[La^-]$ level $\geq 8 \text{ mmol}\cdot\text{L}^{-1}$ and an increased RER [$r \geq 1.0$], elevated HR $>90\%$ of $[220 - \text{participant's age}]$, and a high rate of perceived exertion [visually controlled and case-by-case]; Ribeiro et al., 2016; Sousa et al., 2015).

VO_{2max} and its corresponding speed (vVO_{2max}) showed no significant difference between the intermittent incremental swimming tests ($N \times 200 \text{ m}$) and the continuous 30-minute tests (Cardoso et al., 2002). In addition, VO_2 , v , the stroke length, and the stroke rate obtained in the intermittent incremental tests ($7 \times 200 \text{ m}$) and the continuous 400-m tests were similar, highly associated, and in agreement (Zacca et al., 2019). The comparisons between the VO_{2peak} pairs obtained by back-extrapolation and their associated v at the end of the $6 \times 200\text{-m}$ intermittent incremental swimming test and the 400-m continuous test were also similar, highly associated, and in agreement (Campos et al., 2017). The intensity of the 400-m test (V_{400}) has been used to estimate the MAV for swimming during incremental exercise (Lavoie & Montpetit, 1986). However, VO_{2max} values can also be elicited at intensities above V_{400} (Poole & Jones, 2017).

Assessments of swimmers with impairments have also compared VO_{2max} , obtained in intermittent incremental tests ($N \times 200 \text{ m}$), with VO_{2peak} , obtained in continuous tests (200 m), demonstrating non-different, homogeneous results, considering the proportion of variability in the measurements, and agreement when the v was also similar between the tests (Feitosa et al., 2020). Still, when comparing the intermittent incremental tests ($6 \times 250 \text{ m}$, plus one set of 200 m at maximal intensity) and the continuous tests (in a time-limit session at a MAV until exhaustion) at maximal intensity, the VO_{2peak} values were not different for the group of swimmers (Almeida et al., 2022).

In addition, there were also similarities in the VO_2 results at submaximal intensity when comparing the intermittent incremental tests ($7 \times 200 \text{ m}$, 30-second interval) and the 30-minute continuous tests, when the v was similar for the tests (Pelarigo et al., 2018). In these intermittent incremental tests, VO_2 was obtained at I_{anT} , VT, HRT and $[La^-]$ threshold (LT) while in the continuous tests, VO_2 was obtained at maximal lactate steady state (MLSS), and with correlated v values (MLSS vs I_{anT} , $R^2 = 0.52$; MLSS vs $LT_{3.5}$, $R^2 = 0.60$; however, MLSS vs HRT, $R^2 = 0.22$) between the methods (Pelarigo et al., 2018). MLSS has been considered the gold standard for aerobic assessment and can be defined as the highest intensity of constant load exercise where stability in $[La^-]$ can still be observed (Greco et al., 2010). VO_2 obtained at the LT speed was also similar for the intermittent incremental tests ($7 \times 200\text{-m}$) and the 30-minute continuous tests when v was similar for the tests (Arsoniadis et al., 2020). Thus, continuous 30-minute tests provide an acceptable time to compare variations in physiological and biomechanical parameters in swimming (Fernandes et al., 2011).

Blood lactate concentration

The $[La^-]$ results obtained from the intermittent incremental and continuous tests were different between the studies. Regarding the comparison between the intermittent incremental tests ($N \times 200 \text{ m}$, approximately 29 minutes in duration) and the continuous tests (T30) at a similar vVO_{2max} , $[La^-]$ was higher for the intermittent incremental tests (with an increase in speed at each step) compared with the continuous tests (Cardoso et al., 2002). However, when the intermittent incremental tests ($N \times 200 \text{ m}$) and continuous tests (T30)

took place at the same LT speed, $[La^-]$ was higher in the 30-minute continuous tests. A possible explanation for this difference is a shorter stroke length, a higher stroke rate, and the mathematical model used to obtain the LT of the continuous test, which predicts a margin of error of 2.0%–2.5% in the LT speed, as well as the lack of breaks during the test (Arsoniadis et al., 2020). There were similar $[La^-]$ levels when intermittent incremental tests (7×200 m) were compared with the 400-m continuous tests (Zacca et al., 2019). Finally, there was a difference in $[La^-]$ between the intermittent incremental tests (6×250 m, plus one set of 200 m at maximal intensity) and the continuous tests in a time-limit session at the MAV to exhaustion, with slightly higher values for the intermittent incremental tests compared with the continuous tests for the group of swimmers analysed (Almeida et al., 2022).

The meta-analysis comparing the intermittent and continuous tests at a similar v revealed similar $[La^-]$ results for the tests (Almeida et al., 2022; Greco et al., 2010; Nikitakis et al., 2019). The MLSS was compared between the intermittent tests (12×150 s, 30-second interval) and the continuous tests (T30), with a respective v of $1.26 \pm 0.05 \text{ m} \cdot \text{s}^{-1}$ (based on 89.3 ± 2.0 of %V400) and $1.23 \pm 0.05 \text{ m} \cdot \text{s}^{-1}$ (based on %V400-m, and a 2.5% increase and reduction in the v), with no significant difference for $[La^-]$, which shows that intermittent exercise allows for increased exercise intensity at the MLSS (Greco et al., 2010). Similarly, the comparison between the intermittent tests (10×200 m at a critical speed, 35–45-second interval) and continuous tests (T30 at the MLSS), with a similar v between the tests, revealed similar $[La^-]$ in adolescents (the sample used in the meta-analysis) and children (Nikitakis et al., 2019). The critical speed in adolescents was calculated using the 200-m and 400-m tests (Nikitakis et al., 2019); it was around 5.5% different from the critical speed of adults (Pelarigo et al., 2011).

Additionally, the comparison between the intermittent tests (100 m, 15-second interval) and the continuous tests (time-limit sessions at the MAV until exhaustion, constant load set) with an equal $vVO_{2\text{max}}$ resulted in similar $[La^-]$ for the tests (Almeida et al., 2022). This result indicates that swimmers can develop the MAV or $vVO_{2\text{peak}}$ for a longer time in the intermittent test (100-m, 15 s interval) compared with the continuous test (time-limit sessions at the MAV until exhaustion) without altering $[La^-]$.

Heart rate

The HR results varied between the different tests. When comparing intermittent incremental tests ($N \times 200$ m) with continuous tests (400-m and 30-minute tests), there was no difference in the HR when $vVO_{2\text{max}}$ was similar (Cardoso et al., 2002). There were also similar HR results when $vVO_{2\text{max}}$ was similar between intermittent incremental tests (6×250 m, plus one set of 200 m at maximal intensity) and the continuous tests in a time-limit session at the MAV until exhaustion (Almeida et al., 2022; Zacca et al., 2019). There was no difference in the HR when comparing the intermittent incremental tests ($N \times 200$ m) and continuous tests (T30) at similar submaximal speeds (Pelarigo et al., 2018). However, there was a higher HR in continuous tests (T30) compared with intermittent incremental tests (7×200 m). A possible explanation for this difference is the greater variations in the stroke rate and a shorter stroke length for the continuous tests compared with the intermittent incremental tests (Arsoniadis et al., 2020). Specifically, in swimmers with impairments, the HR was similar but not homogeneous considering the proportion of variability in the measurements between the intermittent incremental tests ($N \times 200$ m) and the continuous tests (200 m) (Feitosa et al., 2020).

When comparing the intermittent and continuous tests, there was no difference in the HR when the v was similar (Almeida et al., 2022; Greco et al., 2010; Nikitakis et al., 2019). When comparing the intermittent tests (12×150 s, 30-second interval) and the continuous tests (T30) with a similar v at the MLSS, there was no difference in the HR, indicating that intermittent exercise allows for an increase in exercise intensity without a large variation in the HR (Greco et al., 2010). The intermittent tests at the critical speed (calculated from the 200- and 400-m tests; 10×200 m, 35–45-second interval, ≈ 30 minutes total) also showed a similar HR to the continuous 30-minute tests based on the MLSS (Nikitakis et al., 2019). The intermittent tests (100 m, 15-second interval, time-limit $1,013.6 \pm 496.6$ s) and the continuous tests (time-limit sessions at the MAV until exhaustion, constant load set, time-limit 256.2 ± 60.3 s) at the same $vVO_{2\text{max}}$ showed a similar HR for swimmers of both sexes (Almeida et al., 2022). The duration of the intermittent tests was similar to or longer than the duration of the continuous tests, because there were intervals between the sets of exercises in the intermittent tests, making it possible to maintain the required intensities for longer (e.g., intensities close to the MAV, with possible gains in $VO_{2\text{peak}}$ or in the intensity of the exercise corresponding to the MLSS), and without major changes in the HR (Almeida et al., 2022; Greco et al., 2010).

It is worth mentioning that intermittent and continuous tests have different methodological characteristics for obtaining physiological parameters in swimming. Although some of these physiological results (VO_2 , $[La^-]$, and HR) are similar between the tests, they are not interchangeable (Campos et al., 2017; Cardoso et al., 2002; Feitosa et al., 2020; Zacca et al., 2019), because in the intermittent incremental tests, $VO_{2\text{max}}$ can stabilise (plateau at $<2.1 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{minute}^{-1}$), despite the increase in v to the point of exhaustion, and meet the primary and secondary criteria for choosing the true $VO_{2\text{max}}$ (Feitosa et al., 2020; Howley et al., 1995; Zacca et al., 2019).

The main limitation of this study was not including languages other than English when searching for articles, and not including articles published in specific books applied to sports swimming. However, these choices are widely accepted by the scientific community.

Practical applications

It is necessary to be careful when choosing the best test given its characteristics – for example, the test duration, load progression (intensity), the number of participants who can perform each specific test depending on its complexity, the financial costs (e.g. equipment for measuring VO_2 , $[\text{La}^-]$ supplements, specific cardiac monitors for swimming), and the work rate applied to the participants (Cooper et al., 1984). Short continuous tests (e.g. 200 m in the case of impaired swimmers, due to the specific duration and intensity of this test for these swimmers, and 400 m for swimmers without impairments) show greater time savings and similar, associated, and concordant results (e.g. $\text{VO}_{2\text{peak}}$ vs $\text{VO}_{2\text{max}}$) when compared with incremental intermittent tests ($N \times 200$ m), and they are valid for prescribing the training intensity (Campos et al., 2017; Feitosa et al., 2020; Zacca et al., 2019). However, when coaches want to measure the true $\text{VO}_{2\text{max}}$, the test must be in the severe intensity domain (Hill et al., 2002), at conditions equal to or greater than the 400-m test velocity, with elevated physiological function of the ventilatory and cardiac systems, with greater recruitment of type II muscle fibres, and with minute-ventilation increases for the ongoing lactacidemia (Poole & Jones, 2017; Ribeiro et al., 2016; Sousa et al., 2015; Whipp et al., 2005).

Although the VO_2 results are similar in various tests with different methods and time durations, but with a similar intensity (v), it is worth noting that small differences between v can provide divergent training intensities, underestimating or overestimating the MAV (Campos et al., 2017). Given the similarities between intermittent and continuous tests for assessing the MLSS in swimming, intermittent tests make it possible to increase the intensity of exercise without significant changing $[\text{La}^-]$ and the HR due to the presence of intervals and with the same duration of training. Thus, prescribing stimulus to improve aerobic capacity is more interesting through intermittent efforts (Beneke et al., 2003; Greco et al., 2010).

Conclusions

In conclusion, this meta-analysis showed that the VO_2 results were similar for the intermittent incremental and continuous tests when the v was also similar and when tests lasted for at least >2 minutes, so more stable VO_2 levels can be achieved. However, the $[\text{La}^-]$ and HR results obtained from the comparisons between the intermittent incremental and continuous tests varied between the studies even when the v was similar. Finally, the intermittent and continuous tests produced similar $[\text{La}^-]$ and HR results when the v was similar and when the duration between the tests was similar or longer for the intermittent tests compared with the continuous tests. When evaluating swimmers without the objective of actually obtaining their $\text{VO}_{2\text{max}}$, short continuous tests (200 m for swimmers with impairments and 400 m for swimmers without impairments) are recommended. However, if the objective is actually to identify $\text{VO}_{2\text{max}}$, then incremental intermittent tests ($N \times 200$ m) are recommended. Short continuous and incremental intermittent tests are valid for to prescribe the training intensity.

Competing interest The authors declare that they have no competing interest, financial or otherwise.

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