

REVIEW
EXERCISE PHYSIOLOGY AND BIOMECHANICS

Is test specificity the issue in assessing aerobic fitness and performance of runners? A systematic review

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ABSTRACT

INTRODUCTION: Various tests have been developed to evaluate aerobic fitness and performance of runners. However, a systematic understanding of which methods are more accurate is necessary to provide coaches and the sports sciences community with useful and confident outcomes. This study aims to summarize the evidence regarding the validity, reliability and sensitivity of tests for measuring aerobic fitness and performance in runners of several background of training.

EVIDENCE ACQUISITION: A systematic search was conducted of Web of Science, PubMed and Scopus up to 31st December 2022 according to PRISMA statement guidelines. Studies that reported findings about tests covering maximal aerobic speed, final velocity achieved during the test, average running speed or other method of evaluating the reference speed during the test were included. We evaluated the risk of bias in the included articles using the Risk of Bias Assessment Tool for Nonrandomized Studies (RoBANS). The tests were categorized into continuous incremental tests, intermittent tests and time-trial test.

EVIDENCE SYNTHESIS: A total of 23 studies met eligibility criteria. These studies contained three background of training: track and road runners (N.=15), trail runners (N.=7) and inexperienced runners (N.=1). Criterion validity was assessed in 73% of the studies, while only 41% of studies examined convergent validity. The majority of the reviewed studies (87%) ignored test–retest reliability. Test sensitivity was not reported in any study.

CONCLUSIONS: At least one aerobic fitness and performance test was identified for each types of background of training. However, some methodological aspects were not provided in the included articles. Most studies examined at least one aspect of validity (*i.e.*, criterion or convergent-related validity), whilst few studies investigated test–retest reliability. Researchers and practitioners can use the information provided in this systematic review to select appropriate tests.

(Cite this article as: Benhammou S, Mourot L, Clemente FM, Coquart J, Belkadi A. Is test specificity the issue in assessing aerobic fitness and performance of runners? A systematic review. J Sports Med Phys Fitness 2023;63:000–000. DOI: 10.23736/S0022-4707.23.15619-2)

KEY WORDS: Running; Reproducibility of results; Systematic review.

Introduction

Endurance running is defined as running several kilometers over a long period of time while employing aerobic metabolism.¹ However, it is important to recognize that “endurance running” encompasses a wide range

of athlete profiles² and performance factors,³⁻⁷ as it may include outdoors running over 5 km to ultramarathons.⁸

Aerobic fitness testing could be conducted out either on the field or in the laboratory for a variety of reasons including overall physiological assessment,⁹ monitoring training and performance,¹⁰ training prescription¹¹ and talent iden-

tification.¹² Due to these multipurpose criteria, one aerobic fitness test may scarcely be employed as the perfect tool that can provide relevant information for all aspects of aerobic fitness testing.¹³ This prompted the creation of various field aerobic fitness and performance tests that usually assess the same fitness quality (*i.e.*, maximal aerobic speed (MAS)), but with different approaches (time-trial test, continuous incremental protocol, intermittent protocol), and various stages duration, increments and starting velocities. Consequently, these tests provide different final speeds depending to the type of effort put forth during the test.¹⁴⁻¹⁶ A critical aspect of this evaluation process is the selection of appropriate tests that provide a reliable and valid assessment of aerobic fitness and performance, because some tests have limited practical.¹³ Similarly, choosing the appropriate test according to the specific runner (as his/her preferred running distance) being evaluated is essential for optimal adaptation to the requirements of the sport. It is well recognized that the selected test should reflect the movement patterns and physiological requirements of the sport in which the athlete competes.¹⁷ In recent years, coaches have increasingly sought reliable and specific tools for assessing endurance runners, leading to a growing number of proposed aerobic fitness and performance tests.¹⁸⁻²¹

There are several background of training.²² Therefore, it is crucial to evaluate the measurement properties of aerobic fitness and performance tests for each category of runners, including reliability (*i.e.*, the consistency and stability of results over repeated rounds of testing),²³ criterion validity (*i.e.*, the capacity of a test to demonstrate good agreement with gold standard protocol),^{24, 25} convergent validity (*i.e.*, relationship between a sport-specific test and another measurement of the same construction or related measurements)^{26, 27} and sensitivity (*i.e.*, the ability of the test to detect the smallest changes in performance).^{28, 29}

The physiological characteristics associated with performance of runners have received particular attention in recent years, with several investigations examining physiological, morphological, biomechanical factors and physiological loads experienced during running.³⁰⁻³⁴ However, to the authors' knowledge, there is no systematic review that collects tests focused on evaluating aerobic fitness and performance in runners of several background of training. By systematically reviewing the evidence on aerobic fitness and performance tests for runners of several background of training, researchers and practitioners can gain a better understanding of the validity and reliability of

each test. This can help them to make more informed decisions when selecting and administering aerobic fitness and performance tests. Additionally, it is important to consider that these tests serve a valuable purpose in tailoring training programs for athletes. A systematic review, which encompasses a range of tests suitable for different runner profiles, can assist coaches and practitioners in selecting the most appropriate testing methods for their specific requirements. This comprehensive review can also facilitate comparisons across studies, allowing researchers to identify recurring trends and patterns in the results of various studies. This, in turn, enables them to draw more substantial conclusions regarding the effectiveness of different aerobic fitness and performance tests.

The purpose of this review is to comprehensively evaluate and summarize the available research on the validity, reliability, and sensitivity of aerobic fitness and performance tests in runners, taking into account the discipline practiced. This review aims to provide guidance for selecting the most appropriate test and their intended use. The review includes field and laboratory tests carried out by runners of several background of training.

Evidence acquisition

Search strategy

The current systematic review was conducted according to PRISMA statement guidelines.³⁵ This review was previously registered on the Open Science Framework with the registration number 10.17605/OSF.IO/6ZJEH on 3rd May 2023.

Eligibility criteria

The PECOS (population, exposure, comparator, outcome, study design) approach was used to establish the eligibility criteria: 1) population: road, track, trail runners or other background of training, from any age group, male or female; 2) exposure: exposed to aerobic fitness and performance tests covering MAS, the maximal velocity at the end of the test, average running speed or other method of evaluating the reference speed during the test; 3) comparator: exposed to field-based test and/or a concurrent laboratorial test; 4) outcome: criterion validity, convergent validity and/or reliability (*e.g.* correlation coefficient; typical error of estimate expressed as coefficient of variation [TEE as CV%]; intraclass correlation test [ICC]) and/or relationship with performance (correlation coefficient); 5) study design: no restrictions in terms of study design.

Information sources and search

A search for relevant articles published up to 31st December 2022 was carried out using PubMed, Scopus and Web of Science (Core collection). We used Boolean operators (AND/OR) in the search process and did not apply any filters or limitations for language and study design to increase the likelihood of identifying relevant studies. We used the following search strategy as the primary method for identifying relevant studies: (“Runners”) AND (“Maximal aerobic speed” OR “Endurance test” OR “Incremental test” OR “Continuous test” OR “Intermittent test” OR “Fitness test” OR “Time trial”). To find potentially eligible studies that were missed by the electronic searches, the reference lists of the papers collected were also manually searched.

Selection process

Two independent reviewers (S.B. and A.B.) extracted information from each study’s title and abstract, and then examined the full-text articles according to the eligibility criteria. Any disagreements about inclusion were resolved by consensus between both authors or with the assistance of a third reviewer (L.M.). The search results were recorded into a Microsoft® Excel spreadsheet, and any duplicates were removed.

Data collection process

The initial data extraction process was conducted by the lead author (S.B.), and two coauthors (A.B. and L.M.) reviewed the extracted data for accuracy and completeness. If important data were missing from a full-text article, the primary author (S.B.) contacted the corresponding author of the study directly via email and/or ResearchGate to obtain the necessary information.

Data items

Study characteristics

Extracted data from each study included test name, test description, environment, background of training, key results (criterion validity, convergent validity, reliability, sensitivity and relationship with performance) and reference speed assessment. A second author helped to resolve discrepancies in terms of validation procedure. Maximal oxygen uptake (VO_{2max}) measurement was considered as a criterion validity. For relationship with performance, correlation coefficient (Pearson’s r) was recorded.

Participant information

The participants were classified according to the Participant Classification Framework,³⁶ which categorizes indi-

viduals based on their competitive level. The framework includes Tier 0 for sedentary individuals (not relevant to our study), Tier 1 for recreationally active individuals, Tier 2 for trained/developmental individuals, Tier 3 for highly trained/national level athletes, Tier 4 for elite/international level athletes, and Tier 5 for world-class athletes.

Test information

Information on test protocols was classified in to three main levels of classification (Figure 1): 1) continuous incremental test; 2) intermittent test; 3) time-trial test. Continuous incremental test is characterized by a progressive increase in intensity.^{37, 38} The category of intermittent tests mainly involves fixed rest periods, while the activity is performed either at a constant intensity or intensity is increased between rest periods.^{20, 37, 39} Regarding time-trial test, the activity represents a fixed-intensity exercise (typically for several minutes), without rest periods.^{18, 40} The characteristics of protocols and how they were used in the included studies are shown in Table I.^{7, 18, 19, 41-49}

Main outcomes

The primary outcomes of interest were MAS and/or final velocity achieved during the test and/or average running speed and/or the reference speed evaluated during the test.

Study risk of bias

Two of the authors (S.B. and A.B.) independently assessed the risk of bias, and any disagreements were resolved through discussion between the authors. The methodological assessment of the included studies was conducted using the Risk of Bias assessment tool for nonrandomised Studies (RoBANS).⁵⁰ Earlier systematic reviews related to sport science have utilized this instrument.^{51, 52} The tool contains six domains: the selection of participants; confounding variables; intervention (exposure) measurement; the blinding of the outcome assessments; incomplete outcome data; and selective outcome reporting. The domains are categorized as “low,” “high” and “unclear” risk of bias.⁵⁰

Evidence synthesis

Study identification and selection

The search strategy yielded a total of 4,642 records from three databases (Web of Science: 2395; PubMed: 2226;

Scopus: 21), and we identified seven additional articles through reference list searches. After removing irrelevant articles, duplicates, and screening titles and abstracts,

we thoroughly evaluated the full texts of the remaining articles. Ultimately, we included 23 articles that met the eligibility criteria for this systematic review (Figure 2).

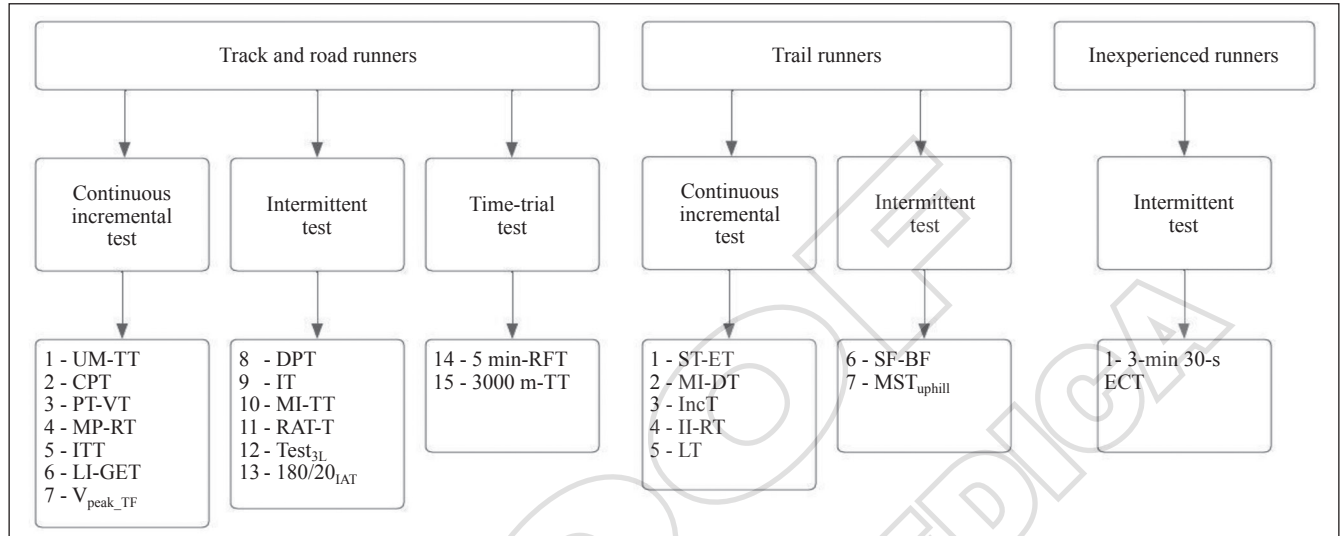


Figure 1.—Description of aerobic fitness and performance tests in the reviewed articles.

3-min 30-s ECT: the 3-minute, 30second endurance capacity test; 5min-RFT: a 5-min running field test; 180/20_{IAT}: the 180/20 intermittent athletic test; 3000m-TT: 3000 m time-trial; CPT: continuous protocol behind a cyclist; DPT: discontinuous protocol; II-RT: the incline incremental running test; IncT: IncremenTrail; IT: incremental test; ITT: incremental treadmill test; LI-GET: laboratory incremental graded exercise test; LT: laboratory test; MI-DT: maximal incremental downhill test; MI-TT: multistage incremental track test; MP-RT: maximal progressive running test; MST_{uphill}: uphill maximal stage test (22% incline); PT-VT: peak treadmill velocity test; RA-T: RABIT test; SF-BF: specific field-based protocol; ST-ET: specific trail exercise test; Test_{3L}: three-level test; UM-TT: the universite de montreal track test; V_{peak_TF}: peak running velocity on the track field.

Protocol category	Description	Illustration
Continuous protocol ^{18, 45}	Exercising continuously while maintaining a fixed intensity throughout the duration of the test	
Continuous incremental ^{7, 41}	Marked by a gradual increase in exercise intensity for several minutes	
Intermittent protocol ^{19, 42-44, 46-49}	Fixed: involving actions carried out at a fixed intensity and rest intervals Incremental: involving fixed rest times, with a gradual increase in exercise intensity between activity bouts	

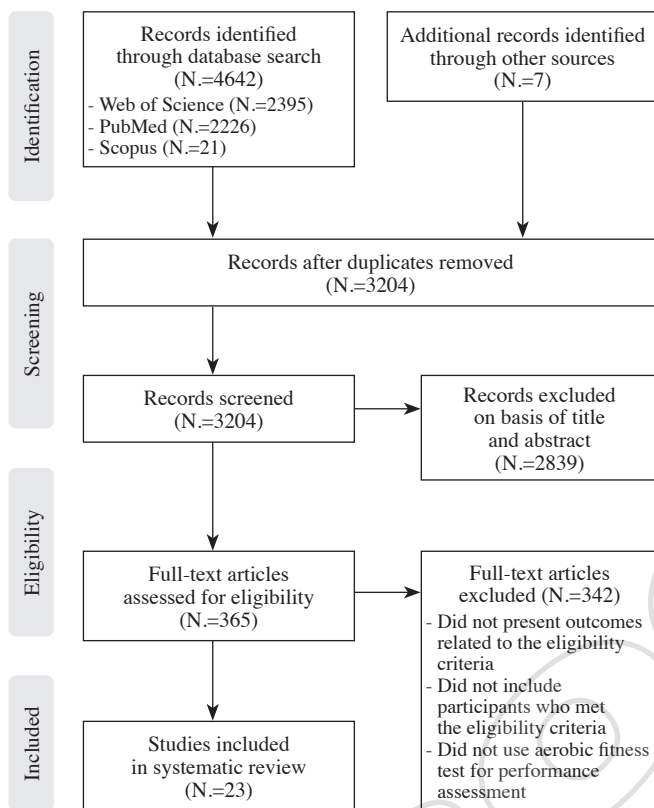


Figure 2.—PRISMA flow diagram showing the selection process for inclusion of articles.

Assessment of methodological quality

Risk of bias assessments for each study is demonstrated in Table II, 7, 18-21, 41-49, 53-60 including the total of each risk category (unclear, low or high). In the majority of the studies, subject characteristics and test execution were clearly depicted. 60% of the articles (14 out of 23) had unclear confounding variables due to the lack of control over physical fitness evaluations and performance measures in relation to environmental details (indoor/outdoor, temperature if outdoor, time during day or a.m./p.m.) or diet prior and across measures (e.g. caffeine, alcohol supplements etc.). The risk of bias in the intervention measurement was high in 26% of the included studies and unclear in 54% of studies because the authors did not make it apparent how the process was identified. None of the studies mention blinding of outcome assessments. In addition, the risk of bias was low for incomplete data in most of the studies.

Characteristics of the included studies and main findings

The MAS is a necessary variable for runners since is a better predictor of performance.^{5, 15} Most of the tests included in this review allow to obtain this speed (directly or indirectly) which makes it possible prescribe training intensity.⁶¹ Continuous incremental tests (field or laboratory

TABLE II.—RoBANS assessment of included studies reporting quality. 7, 18-21, 41-49, 53-60

Study	Selection of participants	Confounding variables	Intervention measurement	Blinding outcome assessment	Incomplete outcome data	Selective outcome reporting
Léger et Boucher ⁵³	Low	Unclear	High	Low	Low	Low
Melin <i>et al.</i> ⁴⁶	Low	Unclear	Unclear	Low	Low	Low
Berthon <i>et al.</i> ¹⁸	Low	Unclear	Unclear	Low	Low	Low
Demarie <i>et al.</i> ⁴⁸	Low	Unclear	High	Low	Unclear	Low
Billat <i>et al.</i> ⁴⁷	Low	Unclear	Unclear	Low	Unclear	Low
Simões <i>et al.</i> ⁴⁵	Low	Unclear	High	Low	Low	Low
Burtscher <i>et al.</i> ⁵⁷	Low	Unclear	High	Low	Low	Low
McLaughlin <i>et al.</i> ⁷	Low	Unclear	Unclear	Low	Low	Low
Schnitzler <i>et al.</i> ⁴²	Low	Unclear	High	Low	Low	Low
Ratray et Roberts ⁴³	Low	Low	Unclear	Low	Low	Low
Lauenstein <i>et al.</i> ⁴⁹	Low	Low	Unclear	Low	Low	Low
Leti <i>et al.</i> ⁵⁴	Low	Unclear	High	Low	Unclear	Low
Machado <i>et al.</i> ⁵⁵	Low	Low	Unclear	Low	Low	Low
Nimmwrichter <i>et al.</i> ⁵⁶	Low	Low	Unclear	Low	Low	Low
Scheer <i>et al.</i> ⁵⁸	Low	Unclear	Low	Low	Unclear	Low
Giovanelli <i>et al.</i> ⁴⁴	Low	Unclear	Low	Low	Low	Low
Lemire <i>et al.</i> ⁵⁹	Low	Unclear	Unclear	Low	Low	Low
Benhammou <i>et al.</i> ¹⁹	Low	Low	Unclear	Low	Low	Low
De Lucas <i>et al.</i> ⁴¹	Low	Unclear	Low	Low	Low	Low
Doucende <i>et al.</i> ⁶⁰	Low	High	Unclear	Low	Unclear	Low
Benhammou <i>et al.</i> ²⁰	Low	Low	Unclear	Low	Low	Low
Manoel <i>et al.</i> ²¹	Low	Low	Unclear	Low	Low	Low

tests) take the last speed obtained as a reference except for II-RT⁴¹ which takes speed at peak inclination (50% of the peak speed obtained during another previous treadmill test), same for intermittent tests except for 3-min 30-s ECT⁴² which takes mean speed of the last 5 run bouts, SF-BP⁴³ which takes the average running speed on the last completed course (803-m), RA-T⁴⁴ which takes maximum running speed as determined by the 3-minute hard pace and Test_{3L}¹⁹ which use an equation to determine MAS. Average running speed is calculated for all time-trial tests.

A total of 517 participants with an average age from 18 to 45 years were engaged, and most studies (79%) included <30 participants. Eighty-six percent of the participants were men and eight percent were women. Six percent of the studies contained no information regarding the sex of the participants. Thirty-five percent of studies included athletes participating at the national or international level, sixty-five of studies blended samples of national/sub-elite and regional/local athletes.

The main characteristics for the articles included in this systematic review are summarized in Supplementary Digital Material 1 (Supplementary Table I). Of the 23 articles included, fifteen articles are about track and road runners^{7, 18-21, 44-48, 53-56} defined as any footrace ranging from 800 m to marathon,⁶²⁻⁶⁴ seven for trail runners^{41, 43, 49, 57-60} defined as a race in a natural environment (*e.g.* mountain) of up- and downhill with minimal possible asphalt road^{65, 66} and one for inexperienced runners⁴² defined as runners who have no experience in middle or long-distance running.⁴²

Of the 23 articles included in this study, nine articles are laboratory tests: eight with gradual and continuous increase in speed^{7, 41, 55-60} and one with intermittent increase in speed.⁴⁹ Fourteen articles are field tests: four with progressive and continuous increase in speed,^{21, 46, 53, 54} eight with intermittent increase in speed^{19, 20, 42-44, 46-48} and two with constant maximum speed.^{18, 45}

Test-retest reliability was examined in only three studies (13%). To assess level of reliability, one study⁵³ utilized correlation coefficient only, and two studies^{19, 42} applied mixed statistical techniques (ICC and TEE as CV%). Test-retest intervals ranged from 2 to 7 days. Criterion validity was assessed in 73% of the eligible studies and 41% of studies investigated convergent-related validity. The majority applied correlation coefficients only, whereas 37% also included correlation coefficients with other approaches (*e.g.*, 95% LOA, ANOVA, paired sample *t*-test). The relationship with performance was investigated in 25% of the studies. Distances ranged from

800 m to semi-marathon (r 0.78-0.97). All studies did not report any details about the sensitivity.

Discussion

This review reports aerobic fitness and performance tests used in runners categorized into continuous incremental tests, intermittent tests and time-trial tests. The study populations were categorized into one of three background of training: track and road runners, trail runners and inexperienced runners. Based on the results, it seems that aerobic fitness and performance can be assessed through these tests, while there is a lack of information on some measurement properties. These results can help coaches and athletes make better decisions to choose best test suited to their needs.

In total, in the current review, 23 different tests that all concern endurance runners have been identified. The oldest were above all “universal” and concerned track and road runners (type UM-TT).⁵³ The most recent ones become very specific for certain populations (trail runners) given the keen interest fans have shown of new practices of running (especially trail-running).⁵⁸ In each category, several different tests were identified (except for inexperienced runners where only one test was identified). Tests numbers in each category may be explained by differences relating to the category of the test (*e.g.* time-trial, intermittent and continuous incremental testing) and test execution as already reported.⁶⁷ For example, time-trial field testing are relatively easy to perform,¹⁸ while laboratory tests require expensive equipment and experienced humans,^{68, 69} which relatively depart from the reality of training for runners⁷⁰ and continuous incremental field tests require speed adjustment to the sound signals.⁷¹

Due to different performance factors between runners of several background of training and the difficulty in gathering specific performance indicators, there is no benchmark test capable of jointly measuring all the determinants of physical performance in running. Physical tests usually focus on measuring one or two physical factors. Whereas relevant assessment requires laboratory tests,⁷² field testing has an accuracy error of ± 10 -15% for estimating maximum aerobic capacity.⁷³

One most important finding that for all the tests identified, no study analyzed all the measurement properties (validity, reliability and sensitivity). Moreover, all identified tests had information on at least one of the measurement properties while only one study⁵⁵ provided no information on these characteristics. In addition, no studies reported information regarding sensitivity. This demonstrates that

there is limited information in the literature of the measurement properties for aerobic fitness and performance tests commonly used in runners. All these findings are interesting because it is recommended in the literature when choosing a testing protocol, three factors must be considered: validity, reliability, and sensitivity.^{28, 74, 75}

Reliability

Numerous concepts such as reproducibility, repeatability, concordance, consistency, agreement and stability, have been used interchangeably with reliability in the literature.⁷⁶ Reliability is the capacity of testing protocol to produce consistent results over repeated testing sessions.²⁷ The majority of the reviewed studies ignored test-retest reliability, except for three studies^{19, 42, 53} that examined this property. Interday reliability represents the most studied specific property (100% of these studies) (Supplementary Table I). Because this can be a limitation, upcoming investigations is required to determine the reliability of other tests identified in this review. Previous studies^{28, 77} recommend using a mixed statistical approach to effectively establish reliability (*e.g.* CV, ICC and the 95% limits of agreement). Two out of three studies that examined reliability applied a mixed approach to examine reliability. Overall, it is advised to calculate test reliability by adopting suitable statistical approaches in order to accurately determine the reliability of test.²⁷ Of note, the sensitivity was surprisingly neglected in all studies.

Validity

Criterion validity was established in most the reviewed studies (73% of the studies). This seems logical since one of the current study's inclusion criteria is to measure the maximal velocity performance at the end of the test (*i.e.* vVO_{2max} measurement) knowing that VO_{2max} measurement was considered as a criterion validity. However, only 41% of the studies addressed convergent validity. To do this, the primary statistical methods used were Pearson's product moment correlation,^{7, 18-21, 41, 42, 44-46, 49, 53, 56, 59, 60} ANOVA,^{18, 42, 43, 45, 47, 54, 57-59} Student's *t* test^{19-21, 41, 44, 48} and the 95% limits of agreement.^{19-21, 41} Therefore, Future research should pay special attention to studying all of the validity properties of aerobic fitness and performance tests in runners.

It is noteworthy that 13% of the studies^{7, 19, 42} addressed both validity and fidelity (*i.e.* in the same study). This remark might represent another gap in the literature because, any newly created protocols must be checked for validity and reliability before being used in intervention studies.²⁸

Track and road runners

Although there are many runners of several background of training, track and road running is the most practiced model among runners.^{78, 79} Therefore, sufficient validity and reliability for aerobic fitness and performance tests are needed. In this review, fifteen tests were found for track and road runners, among which UM-TT is one of the most frequently used tests for its validity.¹⁶ Four studies^{53, 80-82} reported criterion validity which ranged from 0.89 to 0.96 (UM-TT *vs.* VO_{2max}). One study⁵³ evaluated convergent validity. Correlation coefficient with UM-TT was 0.84 (12-min run test). Only one high-quality study⁵³ verified the reliability of the UM-TT in trained and untrained subjects and reported a high correlation coefficients ($r=0.97$). However, much of the information about the reliability of this test is reported in soccer¹³ which explains its wide use in literature. One study⁴⁶ examined CPT and DPT in terms of criterion validity ($r=0.97$, CPT *vs.* VO_{2max} and $r=0.92$, DPT *vs.* VO_{2max}). The authors concluded that CPT provides more accurate vVO_{2max} and VO_{2max} values than DPT. Two studies^{18, 83} examined criterion validity of 5min-RFT (5min-RFT *vs.* VO_{2max}) in different physical fitness levels runners which ranged from 0.69 to 0.90. One study¹⁸ examined convergent validity of 5min-RFT with a correlation coefficient of 0.97 (5min-RFT *vs.* UM-TT). One study⁴⁸ analyzed the criterion validity of MI-TT, one study⁵⁴ of MP-RT and one study⁴⁷ of IT, but the correlations were not reported. Other statistical approaches were used (*e.g.* analysis of variance ANOVA and Student's *t*-test). A correlation coefficient of 0.71 (3000m-TT *vs.* continuous velocity-incremented test) was found in one study⁴⁵ that looked at the convergent validity of the 3000m-TT. One study⁷ examined the criterion validity of PT-VT and reported a correlation coefficient of 0.89 (PT-VT *vs.* VO_{2max}). On study⁵⁶ analyzed the criterion validity of LI-GET ($r=0.79$, LI-GET *vs.* VO_{2max}). For the RA-T, one study⁴⁴ evaluated its convergent validity ($r=0.88$, RA-T *vs.* graded exercise test). One study²¹ evaluated convergent validity of V_{peak_TF} and one study¹⁹ of Test_{3L}. Convergent validity was 0.94 for V_{peak_TF} *vs.* V_{peak} based on the laboratory treadmill test and 0.93 for Test_{3L} *vs.* UM-TT. The reliability of the Test_{3L} was also studied,¹⁹ where this test exhibited a high relative reliability (ICC of 0.99). One study²⁰ reported convergent validity of the 180/20_{IAT} with a correlation coefficient of 0.82 (180/20 *vs.* UM-TT). It had also been noted that the 180/20_{IAT} can be used as a training session because is tailored to the middle distance runners' training mode (intermittent exercises). Nevertheless, further research is needed to determine their criterion validity. However, caution is required when using

ITT as no measurement properties were reported for this test. In other words, nine tests (UM-TT, CPT, DPT, 5min-RFT, MI-TT, IT, PT-VT, MP-RT and LI-GET) were subjected to criterion validity and seven tests (UM-TT, 5min-RFT, 3000m-TT, RA-T, Test_{3L}, 180/20_{IAT} and V_{peak-TF}) to convergent validity. However, only three studies (UM-TT, 3-min 30-s ECT and Test_{3L}) achieved good results regarding reliability. The relationship with performance was looked into six studies^{7, 18, 20, 21, 55, 56} (r 0.78-0.97).

Another crucial point is that the total test duration is important in the evaluation of runners' aerobic fitness and performance.¹⁹ In addition, it is recommended to give preference to short duration tests with inexpensive equipment to obtain a true maximal physiological parameter.⁸⁴ Some tests have these qualities. This is apparently the case of Test_{3L}.¹⁹ This test of short duration and simple to perform, offers three protocols to three categories of runners: beginner, trained and elite, unlike many other tests. It is noteworthy that, future research should examine the validity of this technique in runners (notably for women) to broaden its relevance within the endurance sports.

Trail runners

In recent decades, there has been a sharp increase in the number of amateur athletes who practice trail running.^{85, 86} It is therefore of interest to coaches to find exercise testing to enhance training concepts and predict performance. There were seven tests identified in this review estimating aerobic fitness and performance of trail runners: ST-ET, MI-DT, IncT, II-RT, LT, SF-BF and MS_{uphill}. All tests were performed on a motorized treadmill in the laboratory except for SF-BF which was carried out in the field. Therefore, the tests that have been carried out in a laboratory require relatively expensive equipment. These tests showed high criterion validity values (r 0.83-0.99) and appear to be accurate, as they best match the requirements of trail running. They were carried out with constant gradient slope or continuous increase in inclination since trail running

encompassing downhill and up-hill running. One study⁵⁹ reported convergent validity of the MI-DT. vVO_{2max} in MI-DT was correlated to vVO_{2max} in level running test and uphill running test ($r=0.80$ and $r=0.81$, respectively). One study⁴¹ evaluated convergent validity of II-RT. Convergent validity was 0.70 for II-RT vs. incremental step test based on the laboratory treadmill. One study⁵⁷ investigated criterion validity of the LT. One study⁴³ examined SF-BP in terms of criterion validity. The criterion validity of MST_{uphill} was also assessed in one study.⁴⁹ The coefficient of validity for men and women was 0.85 and 0.84, respectively. However, there were no studies testing the reliability, sensitivity and relationship with performance of these tests. There is still need studies evaluating the measurement properties of these tests in trail runners.

INEXPERIENCED RUNNERS

Running remains one of the most practiced types of physical activity in the world, attracting individuals all skill levels including inexperienced runners.⁸⁷ Only one test (3-min 30-s ECT) was identified in this review. The convergent validity of 3-min 30-s ECT was investigated in one study with a correlation coefficient of 0.76 (3-min 30-s ECT vs. UM-TT). The test-retest procedure indicated that 3-min 30-s ECT is highly reproducible (coefficient of variation of 1.99 and ICC of 0.98). There was no evidence on sensitivity for the test. This test consists of 10 run bouts of 3 min with 30s of recovery between races, which presents an expensive way in terms of time. In addition, subjects are asked to run at 75% of MAS (first 5 bouts) that has been previously determined, which implies to perform another test beforehand.

Practical applications

Based on the results of this review, a standardized and reliable set of tests can be recommended for assessing aerobic fitness and performance in runners of several background of training. Table III summarizes the valid and reliable tests identified in the studies included in this review.

TABLE III.—Valid and reliable aerobic fitness and performance tests for runners of several background of training.

Background of training	Test that can be considered valid	Test that can be considered reliable
Track and road runners	UM-TT, CPT, DPT, PT-VT, MP-RT, LI-GET, V _{peak-TF} , IT, MI-TT, RA-T, Test _{3L} , 180/20 _{IAT} , 5min-RFT, 3000m-TT	UM-TT, Test _{3L}
Trail runners	ST-ET, MI-DT, IncT, II-RT, LT, SF-BF, MST _{uphill}	
Inexperienced runners	3-min 30-s ECT	3-min 30-s ECT

3-min 30-s ECT: the 3-minute, 30second endurance capacity test; 5min-RFT: a 5-min running field test; 180/20_{IAT}: the 180/20 intermittent athletic test; 3000m-TT: 3000 m time-trial; CPT: continuous protocol behind a cyclist; DPT: discontinuous protocol; II-RT: the incline incremental running test; IncT: IncrementTrail; IT: incremental test; LI-GET: laboratory incremental graded exercise test; LT: laboratory test; MI-DT: maximal incremental downhill test; MI-TT: multistage incremental track test; MP-RT: maximal progressive running test; MST_{uphill}: uphill maximal stage test (22% incline); PT-VT: peak treadmill velocity test; RA-T: RABIT test; SF-BF: specific field-based protocol; ST-ET: specific trail exercise test; Test_{3L}: three-level test; UM-TT: the universite de montreal track test; V_{peak-TF}: peak running velocity on the track field.

It is important to note that the choice of the test should be based on the specific goals and characteristics of the individual athlete, as well as the context in which the test will be performed (e.g., training or competition). Coaches and practitioners should also consider the reproducibility and validity of the test when designing training programs and making decisions based on the results. Coaches can use the data obtained from these tests to identify areas where the athlete needs improvement in order to develop training programs tailored to the specific needs of the athlete, with the goal of maximizing their performance potential. This may entail adjusting intensity, frequency and training volume as well as including specific exercises to address weaknesses discovered during in the testing process. By repeating aerobic fitness and performance tests at regular intervals, coaches can be monitoring an athlete's progress over time, evaluate the effectiveness of training programs and adjust their training programs accordingly.

Limitations of the study

There are certain inherent limitations that need to be considered. Most studies omitted the reliability and sensitivity, and since these are important measures, the results obtained must be interpreted taking into account these aspects.²⁸ In addition, this review could not accurately differentiate between track and road runners and inexperienced runners. From a practical standpoint, inexperienced runners can also run on track and road. Another limitation may be sample sizes where a relatively large number of studies included in this review used small sample sizes, which may limit the generalization of the results. Moreover, few studies tested elite runners, which makes it challenging to predict how these tests will be handled in situations where these runners are involved. Further, it is likely that tests currently exist in theses, reports, or conferences that have not been reviewed here because only original articles were included. Thus, future research should focus on finding ways to make aerobic fitness and performance tests more accessible and less burdensome involving diverse populations to ensure that the results obtained are accurate and reliable across a wide range of athletes.

Conclusions

This review identified 23 aerobic fitness and performance tests commonly used among runners divided into three background of training. These include tests for track and road runners, trail runners and inexperienced runners. All categories had several measurement tests except for

inexperienced runners where we identified only one test. Compared with convergent validity, criterion validity was the measurement characteristic most frequently analyzed across the included studies. In addition, despite its critical importance, few studies investigated test–retest reliability, whilst the sensitivity was not reported in any study. No test was examined in terms of all measurement properties. Therefore, future research in aerobic fitness and performance testing should adopt more rigorous validation processes by addressing validity, reliability and sensitivity. This will increase the applicability, generality, and accuracy of the outcomes obtained from these tests, which will ultimately lead to a better understanding of aerobic fitness in runners. Although each of these tests have their advantages and disadvantages, coaches are advised to know the precise applications of these tests and especially to be able to make an adequate interpretation in order to choose the test closest to the sports practice. Such an assessment deserves to be prepared as a competition.

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Conflicts of interest

The authors certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

Authors' contributions

Saddek Benhammou, Laurent Mourot and Filipe Manuel Clemente conceived the study and search strategy. Saddek Benhammou and Adel Belkadi conducted the systematic review and performed the data analysis. Saddek Benhammou and Adel Belkadi performed the risk of bias assessment. Saddek Benhammou drafted the initial manuscript. Filipe Manuel Clemente, Laurent Mourot and Jeremy Coquart revised the manuscript. All authors read and approved the final version of the manuscript.

Acknowledgements

The authors are particularly grateful to the research center EPSI (Exercise, Performance, Santé, Innovation) of the university of Franche-Comté for its help and support. We also thank Directorate General for Scientific Research and Technological Development (DG—RSdT).

History

Article first published online: _____ - Manuscript accepted: November 20, 2023. - Manuscript revised: November 9, 2023. - Manuscript received: September 26, 2023.

Supplementary data

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