THOUSAND WORDS ABOUT...

DOI: https://doi.org/10.20883/jms.344

A thousand words about running fitness tests

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ABSTRACT

Running is undertaken for different reasons, including improvement or maintenance of health and fitness. Many tests are employed for the estimation of the fitness in runners. In this review, we describe five field tests (Cooper test, Conconi test, 6-Minute Walk Test, 20-meter Multistage Fitness Test, and Harvard Step Test) and one laboratory cardiopulmonary exercise test (CPET) on a treadmill. A properly selected fitness test may help to estimate or measure the maximal oxygen consumption (VO_2), thresholds for the aerobic and anaerobic metabolism, or restitution after the exercise. Such information is used for planning the training process, monitoring the progress of physical fitness or predicting the target distance or speed during competitions. In patients with cardiovascular or pulmonary diseases, this information may help to plan the intensity of daily activity or physical rehabilitation. Testing physical fitness is challenging, however when made appropriately, it delivers valuable physiological and clinical information.

Keywords: aerobic exercise, anaerobic exercise, cardiopulmonary exercise test, physical fitness, running, VO_2.

Introduction

Walking, running, cycling, swimming or physical labour are typical examples of physical activity, i.e. sustained body movement increasing energy expenditure [1, 2, 3]. If physical activity is undertaken to improve or maintain health and fitness, then it is called as an exercise [1, 2, 3]. Exercise is usually performed on a regular, repeated basis with a different frequency, duration and intensity. Exercise improves muscular strength (e.g. resistance training in powerlifting or bodybuilding), balance (e.g. tai chi) or flexibility (e.g. yoga) and is beneficial for the cardiovascular and respiratory physical fitness [3].

Physical fitness is defined as the ability to perform various aspects of sports, occupations and daily activities based on physical effort but without undue fatigue [3]. Different features of physical fitness may be quantified, for instance, aerobic fitness, muscular strength and endurance, flexibility, and body composition. In this review, we focus on selected tests applied to estimate physical fitness in runners.

For runners, cardiovascular endurance or aerobic fitness corresponds to the ability to jog or run continuously for an extended period without a lot of fatigue. The intensity of the running may range from low to high, and it depends mainly on the aerobic, i.e. requiring oxygen, metabolic processes generating energy [1, 5].

Many tests are employed for the estimation of the fitness in runners, from simple field tests (**Tables 1**, **2**, **3**) to a set of laboratory procedures and examinations with the cardiopulmonary exercise test (CPET) on a treadmill as the most advanced (**Table 4**) [4, 5]. The selection of a proper test should be based on the purpose of the research,

the target group (healthy vs sick people, amateurs vs elite runners), and the nature of the sporting effort, depending on its intensity and duration, reliability, costs and ease of use [1, 2, 4, 10].

It is possible to assess the effectiveness of the training, its intensity and applied loads (e.g. total mileage) by comparing the results of several tests performed at different phases of preparation for the competition. Adaptation to the repeated training can be assessed in runners in top sports laboratories that use specialised and expensive equipment, for example for the CPE) to measure the maximal muscle oxygen consumption (VO_{2max}) [5]. However, such tests are not necessary for all runners, and the majority of them can be examined in the gymnasium or track and field through the use of simple, functional field tests [1, 2, 4]. For some of such tests, different formulas allowing the estimation of VO_{2max} have been developed.

Field tests are used for people at the different level of physical fitness, from low to high, in enthusiasts of recreational running, jogging, Nordic walking, amateur and elite runners [1, 2, 4]. The field tests usually do not require specialised equipment. The main rule is to perform the test on a track or route with a precisely measured distance with the use of a stop- or sport-watch or to measure the distance covered in a specific time [4]. For many years, the pulse rate has been measured manually by counting the number of pulsation over carotid or radial artery. In recent years, it has also become possible to quantify heart rate more precisely, during and after the fitness test, even without interrupting physical activity [4, 6]. The heart rate can be measured by so-called heart rate monitors which are strips placed on the chest. Another solution with increasing popularity is the use of wearable devices, smart and sports watches which have special infrared sensors measuring the capillary pulsation that usually equals to the heart rate [6]. For some tests performed in specific populations, e.g. patients with pulmonary or cardiac diseases, equipment to measure blood oxygen saturation (sO_2) is required for example during the CPET or the 6-minute walk test [5, 7].

Field tests

Each type of field test has its purpose. For the Walking/Running Tests — subjects are either walking or running as fast as possible for a specific time (e.g. exactly 6 or 12 minutes) or a set distance (e.g. 400 m, 1 km, 1 mile, 5 km etc.) [1, 2, 4, 7–21]. In the Maximal Aerobic Tests, the exercise is continued until exhaustion, which means it must cover the aerobic capacity and reach the anaerobic level [1, 2, 4, 8, 10]. In case of the Intermittent or Interval Tests, also performed until exhaustion, the consecutive stages with continuous running are separated by periods of either rest or substantial slowing down of the running pace [4, 10, 16–18]. Finally, in Step Tests, the principal element is repeated stepping up and down on the platform at a given rate for either a certain time or until exhaustion [1, 2, 4, 19–21].

Table 1 lists different types of field tests performed in runners with some examples of specific tests. **Table 2** summarises the methodology, types of subjects, advantages and disadvantages of the

Table 1. List of the most popular field tests for runners [1, 2, 4, 9–11, 13, 16, 19]

Types of tests	Examples of tests
Running/Walking Tests	Cooper 12 minutes RunTest
	1-km Run
	Conconi Test
	6-Minute Walk Test
	Rockport Walk Test
Maximal Aerobic Tests	20-meter Multistage Fitness Test (MSFT) (shuttle run test, beep test)
	Yo-Yo Endurance Test
	Maximal Oxygen Consumption Test (VO_{2max})
Intermittent (Interval) Tests	Interval Shuttle Run Test (ISRT)
	The Yo-Yo Intermittent Tests
	Gacon Test (Running 45''/15'')
Step Tests	Harvard Step Test
	Step in Place

most popular field tests for runners. **Table 3** explains how the most popular five different field tests can be performed. Parameters measured during the selected field tests are described in **Table 4**.

The Cooper 12-minute Run Test is the easiest way to measure physical performance in healthy people. The distance covered during the test is compared with the data included in the special table, taking into account the sex and age of the examined person [8]. The Cooper test can be used to: measure the actual physical performance and predict its potential in response to training, measure improvement related to training and even as a way for athlete's motivation [4, 9, 10].

The Conconi test is applied to estimate individual anaerobic threshold during a continuous running with gradually increasing speed. The test results are shown as a value of heart rate and speed above which running is continued in anaerobic conditions. By subtracting 20 beats from the anaerobic threshold for heart rate, the aerobic threshold can also be estimated [4].

The six-minute Walk Test (6MWT) is an adaptation of the Cooper's 12-minute run test for

Table 2. Basic technical requirements, rules of scoring, subjects, advantages and disadvantages of the most popular field tests for runners [1-4, 7, 18].

Test	Equipment	Scoring	For Whom	Advantage	Disadvantage
Cooper 12-minute run test	Running, optimally, on a 400-m track, marks every 50 meters, stop-watch, heart rate monitoring device.	Individual endurance estimated by specially developed tables - Cooper test norm tables, specific for age and gender. Different criteria for professional athletes.	Professional & amateur runners. Can be done as a walking test for unable to run.	Simple and cheap, possibility to simultaneously test a large number of people. Very well studied in athletes.	Practice required. Motivation may affect the result.
Conconi Test	Running, optimally, a 400-m track, marks every 200 meters, stop-watch, heart rate monitoring device.	Anaerobic threshold determined from the graph showing the relation between running speed and heart rate. The deflection point on this graph (flattening of the heart rate after linear increase) indicates the athlete's anaerobic threshold in beats/ minute.	For endurance sports athletes who can perform maximal effort. Mainly for the elite and top amateur runners.	One of the most precise field test to determine the anaerobic threshold in natural conditions.	An experienced coach or trainer. Practice required. Special form, application or formula in excel or other software allowing to make X-Y graphs.
Six-minute Walk Test	Stopwatch, measuring tape or a flat corridor of at least 30-m length, chairs for resting.	The distance covered during the 6-minute walk.	Seniors who are unable to participate in traditional fitness tests. Patients with cardiac and pulmonary disease.	Simple and cheap, very well studied in clinical conditions.	Testing one person at a time. Not designed for very fit people. Running is forbidden, but brisk walking is enhanced.
20-meter Multistage Fitness Test (MSFT)	Flat surface, marking cones, measuring tape, beep test audio, music player, recording sheets.	The completed level and number of the twenty-meter shuttles.	Sports groups, children & adolescents, healthy people; adults with quite high physical capacity.	Simple and cheap, possibility to simultaneously test a large number of people. Attractive can be performed in the form of the competitive game. Very well studied in target populations.	The necessity of using electronic equipment and anti-slippery surface. Type of shoes has a large impact on the result.
Harvard Step Test	step or a gym bench of 45 to 50.8 cm height, metronome, stopwatch, heart rate monitoring device.	The Fitness Index score is determined by measuring pulse or heart rate 1, 2 and 3 minutes after completion of the test.	Useful in endurance sports, better for an amateur than professional athletes.	Self – administrated, simple and cheap, minimal equipment is required. A few people can be tested at the same time.	Individual biomechanical characteristics modify the results - easier for taller people.

people who are unable to run. In contrast to the Cooper's test, there is no warming-up and running is forbidden (for those who can run, other tests, e.g. Cooper's test, should be applied). It is used to evaluate the functional fitness of older people and patients with chronic disorders of the respiratory tract and lungs (for example chronic obturatory pulmonary disease) or the heart (heart failure of different causes) [7, 11–14].

The 20-meter Multistage Fitness Test (MSFT) is usually performed in young participants (children, adolescents), fit people and athletes. There are 23 levels with several repetitions of a series of 20-meter shuttles. The duration of shuttles during the first level corresponds to the speed is 8.5 km/hour (or tempo of 7 minutes and 4 seconds for 1 km) and increases by 0.5 km/hour at every next level [4]. Each level lasts about 1 minute, and there is an increasing number of the shuttles from 8 shuttles in the first level to 16 shuttles in the last level (due to shorter duration of each shuttle with increasing running speed). [4, 16–18].

Harvard Step Test is a test based on the analysis of the heart rate recovery after the repetitive stepping up and down for 5 minutes. It is a good tool to measure fitness efficiency and

Table 3. Summary of instructions on "How to do" selected types of field tests for runners [1-4,7,18].

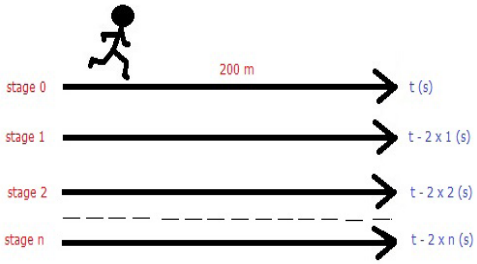
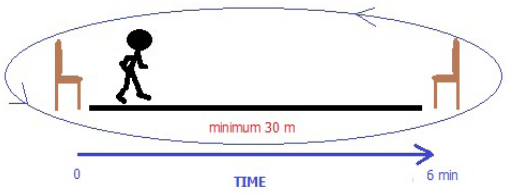
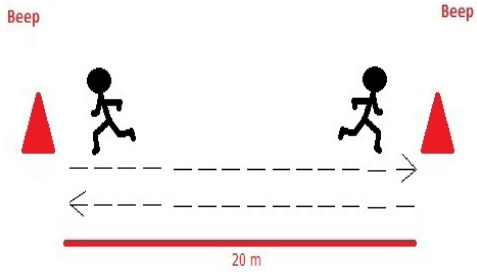
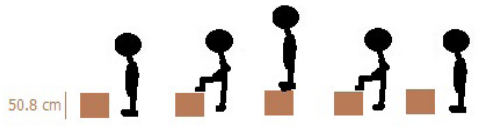
Diagram how to do the test	Description of the test
	*The Cooper test* Warming up for 10 minutes before the test. After the command "GO", the stop-watch is started and the subject commences the test by running for 12 minutes as fast as possible. The assistant informs the subject of the remaining time of running. After the 12 minutes, the test is stopped and the covered distance measured.
	*The Conconi test on a 400-m Track* Warming up for 5 to 10 minutes before the test. After the command "GO", the stop-watch is started and the subject runs gradually increasing the running speed every 200 meters, for example by cutting the duration for each 200-m by 2 seconds. The assistant informs about the duration of the last 200 meters. The increase in speed is maintained until the athlete is unable to accelerate. The starting speed and acceleration between the 200-m stages should be individually adjusted. The diagram on the left shows that the duration of each 200 m is shortened by 2 seconds. Usually, the covered distance is between 2.5 km and 4 km. The measured heart rate is plotted against the speed on the X-Y graph for the determination of the anaerobic threshold.
	*The six-minute walk test* Flat, straight corridor of at least 30-meter length with turnaround points. The patient rests in a chair for at least 10 minutes before the test. Heart rate and pulse oxygen saturation (sO_2) should be monitored continuously. Instruct the patient about walking as fast as possible for 6 minutes, but not running. Encouragements should be provided every one minute. At the end of the test, mark the spot where the patient stopped on the floor. Measure the pulse rate and SpO2 if possible. Calculate the distance walked.
	*The Beep Test* The participant is familiarised with the rules and warms up. Then, the athlete should: run after the beep from the first to the second marker and get there before the next beep sounds; wait for the next beep to run back to the first marker; This sequence is repeated for each shuttle until the participant is unable to keep up with the beeps. A warning is given to the participant for the first fail when the marker line is not reached. The second warning eliminates the participant from the test. The level and number of 20-meter shuttles reached before exclusion is used as the test's score.
	*The Harvard Step Test* The subject steps up and down on the platform at a rate of 30 steps per minute for 5 minutes or until exhaustion (an inability to maintain the stepping rate for 15 seconds). On completion of the test, the subject immediately sits down. Heart rate is counted after 1, 2 and 3 after finishing the test.

Table 4. Parameters measured in the most common field tests and their potential correlation with VO_2

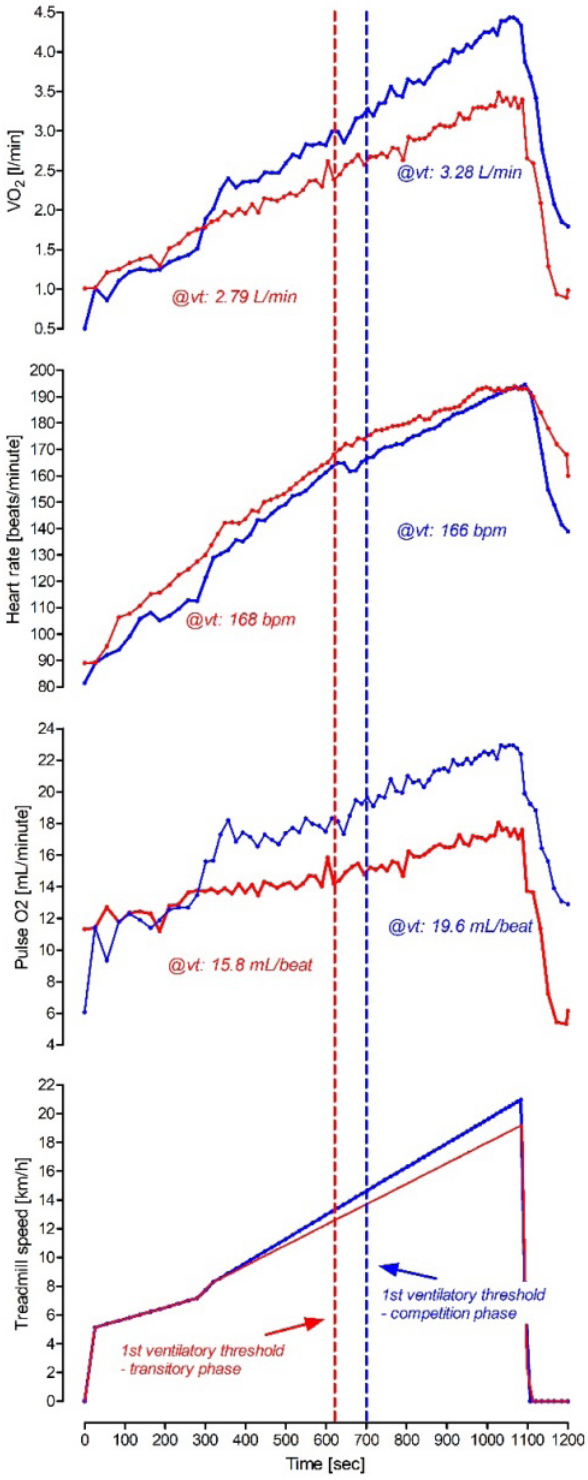
Test name	Measured parameters	Correlation with VO_2
Cooper 12 minutes Run Test	Distance covered by running in 12 minutes; Estimated VO_2max (in ml/kg/min): eVO_{2max} = (distance - 504.9)/44.73	High correlation with VO_{2max}, r = 0.90 [10].
Conconi Test	Continuous recording of heart rate. Averaged values of heart rate for each run 200-m is plotted against the running speed. The deflection point of the running speed – heart rate relationship is considered as the anaerobic threshold.	It is not designed for the VO2 estimation. The main goal is to estimate the anaerobic threshold. However, there are sparse data on the strength of the relationship between this test and the anaerobic threshold from weak to very strong [22].
6 Minute Walk Test	Distance covered by brisk walking in 6 minutes;	This test elicits peak VO_2 similar to that observed during the CPET test but at the lower ventilatory requirements. Weak to moderate strength correlation (r = 0.4–0.8) with VO2 in patients with lung diseases. May co-predict 79–82% of measured VO_{2max} in women and men. An independent predictor of mortality, morbidity and risk of hospitalisation in patients with chronic respiratory diseases, heart failure [7, 13–15].
20-meter Multistage Fitness Test (MSFT)	Level of the test Estimated VO_2max	High correlation with the actual VO_{2max} for adults r = 0.95–0.975 and for children and adolescents r = 0.89 [16–18]. The Beep VO_{2max} Calculator estimates the VO_{2max} score equivalents for each level of the test.
Harvard Step Test	The fitness index score ***Fitness Index*** (short form) = (100 x test duration in seconds) divided by (5.5 x pulse count between 1 and 1.5 minutes). ***Fitness Index*** (long form) = (100 x test duration in seconds) divided by (2 x sum of heartbeats in the recovery periods).	Moderate (r = 0.66 – 0.72) to very strong correlation (r = 0.92) with VO_{2max} in adults of low fitness level [4, 18, 23, 24].

participant's ability to recovery after a vigorous exercise. The more quickly heart rate returns to the pre-test level, the more fit is the person or the better is restitution after the exercise [19–21].

Cardio-Pulmonary Exercise Test

The Cardio-Pulmonary Exercise Test (CPET) is a non-invasive method used for assessing physical performance [1, 2, 5, 10, 25, 26]. The CPET test allows examining the function of the cardiovascular and respiratory systems under strictly defined conditions of metabolic stress, which is caused by a physical effort with a gradually increasing load over time. The CPET helps to estimate approximate thresholds between aerobic (1st ventilatory threshold or anaerobic threshold), mixed (aerobic-anaerobic), and anaerobic metabolism (2nd ventilatory threshold or the respiratory compensation point — RCP). A set of parameters is continuously measured (**Table 5**) through either heart rate monitor or ECG (heart rate), a sensor for sO2, and analysis of partial concertation of oxygen and carbon dioxide (CO_2) in the breathing air as well as tidal volume and respiratory rate. Among the measured parameters are muscle oxygen consumption (VO_2), production of CO_2 (VCO_2) or $pulseO_2$. This test is regularly employed in elite runners, particularly medium and long-distance runners, triathlonists. In modern coaching of runners, results of CPET are used to determine the training loads to increase the effectiveness of the training [10, 25, 26]. The CPET is also used in clinical practice in patients with advanced pulmonary and heart diseases (e.g. potential candidates for heart transplantation) or to diagnose undetermined dyspnoea. The test can be made on a treadmill or cycle ergometer [5].

In summary, physical fitness has many features and can be assessed by dozens of tests. Such tests should be carefully selected, according to specific reasons for their performance and the features of physical fitness to be tested. The decision about the test choice should also be based on the studied population and the availability of the test. Some tests are better to test endurance; some examine the aerobic or anaerobic metabolism and other post-exercise restitution. The field test for runners cover most of these issues



Abbreviations: @vt — at the ventilatory threshold; O_2 — oxygen; VO_2 — oxygen consumption; pulse O_2 — oxygen pulse defined as a ration of VO_2 to heart rate — it corresponds to the left ventricular stroke volume (depends on myocardial contractility) and arterio-venous oxygen difference. Usually, the arterio-venous difference in oxygen concentration does not change a lot during exercise

Figure 1. Sample results of two cardiopulmonary-exercise tests performed in the same 38-year-old male elite long-distance runner during the transitory phase (red curves and descriptions) and the competition phase (blue curves and descriptions) separated by ten weeks of systematic training. During the 10-week training period, the runner gradual increased his running load from 80 to 200 km a week. At this time, his maximal normalised VO2 increased from 57.1 to 71.4 mL/min/kg. There are visible changes in the presented parameters — the training caused a significant improvement in VO_2 and pulse O_2 curves with the lowering of the heart rate curve. Both CPET tests were performed using the individualised ramp protocol, after the 5-minute warm-up, the angle to the treadmill elevation changed from 0 to 1%. The speed of the treadmill started at 8 km/h, and then it changed 0.1 km/h every 7 seconds during the transitory phase and every 6 seconds during the competition phase

Table 5. Parameters measured during the cardiopulmonary exercise test using a treadmill [5, 25, 26]

Parameter	Description
Bf	Breathing frequency (breaths/minute)
HR	heart rate (beats/minute)
MET	metabolic equivalent; expressing work done as a multiple of resting energy expenditure. 1 MET equals 3.5 ml/min/kg of VO_2
O_2Pulse	Oxygen pulse, i.e. the ratio of VO_2 to heart rate. This parameter is proportional to the arterial-venous difference in oxygen pressure and stroke volume
$PETCO_2$	end-tidal partial pressure of carbon dioxide (mmHg)
$PETO_2$	end-tidal partial oxygen pressure (mmHg)
RER	respiratory exchange ratio
VCO_2	carbon dioxide production (l/min)
VE	minute ventilation (l/min)
VE/VCO_2	minute ventilation/carbon dioxide production
VE/VO_2	minute ventilation/oxygen consumption
VO_2	Oxygen consumption (l/min)
VO_2/kg	Oxygen consumption normalised to body weight (ml/min/kg)
Vt	Tidal volume (ml)

— but for patients with chronic heart or pulmonary diseases, they may not be best fitted. In all cases, i.e. elite athletes, amateur runners and in patients with different diseases, the most accurate and detailed is the CPET. However, this test should be performed with the use of an individualised exercise protocol that takes into consideration the potential level of fitness and the maximal walking or running speed sustainable by the examined person for a couple of minutes.

Acknowledgements

Conflict of interest statement
MF receives a scholarship within the Implementation Doctorates Program from the funds of the Ministry of Science and Higher Education, Warsaw, Poland. Project number 0084/DW/2018/02.

Funding sources
This review is a part of the project 0084/DW/2018/02 realised within the "Implementation Doctorates Programme" from the funds the funds of the Ministry of Science and Higher Education, Warsaw, Poland.

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Acceptance for editing: 2019-08-15
Acceptance for publication: 2019-09-10

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