Predicting Oxygen Consumption

You can predict clients' oxygen consumption — a good measure of their physical fitness — without expensive laboratory testing.

By Matt Brzycki

Oxygen consumption is considered the best indicator of a person's level of aerobic fitness.[4] Like virtually all of a person's other physiological characteristics, potential for aerobic fitness is greatly influenced by genetics. Oxygen consumption is also affected by age, gender and body size.

There are a number of ways to accurately measure oxygen consumption in a laboratory. The most widely used method is the motor-driven treadmill. Other methods are stepping up and down on a bench of standard height at a fixed rate, or pedaling a bicycle ergometer (a device that measures work) in an upright or a recumbent position using the legs and/or arms. Each of these methods makes it possible to exercise at different levels of intensity while maintaining a relatively stable position. This allows for measurement of various physiological responses, including the amount of expired air, heart rate, blood pressure and body temperature — all of which can help determine the amount of oxygen being consumed.

A field test, like the 1.5-mile running test, has good correlation to laboratory test results while being easy and cost-effective to perform.

Laboratory testing is an excellent means of providing accurate and valid data. For the average person, however, such tests can be expensive, time-consuming and impractical. A much more practical way to assess oxygen consumption without the drawbacks of laboratory testing is field testing performed outside the laboratory. Certain field tests have a high correlation to laboratory test results.

One of the most popular field tests used to determine oxygen consumption is the 1.5-mile running test. (A 1-mile running test is more suitable for adolescents and the elderly.) The primary objective of this test is to run 1.5 miles in the least amount of time. For this field test to be as accurate as possible, distance must be precise and running must take place on a level surface. Running on an indoor or outdoor track is preferred. While the results of the 1.5-mile running test are an excellent predictor of oxygen consumption,[3] it's important to realize that this test favors runners.

Table 1 lists predicted values of oxygen consumption based on the time it takes to run 1.5 miles. Various running times are given in five-second intervals between eight minutes and 15 minutes 55 seconds. These values are an absolute measure of how much oxygen is consumed in milliliters per kilogram of bodyweight per minute (or ml/kg/min). Table 2 shows norms for oxygen consumption in absolute terms based on age and gender.[2,6]

Oxygen consumption: Absolute

Let's suppose that a 35-year-old man ran 1.5 miles in 12 minutes 30 seconds. Using Table 1, his oxygen consumption for this particular running time is 42.12 ml/kg/min, or simply 42.12. In other words, he consumed about 42.12 milliliters of oxygen for every kilogram that he weighed during each minute of his 1.5-mile run. Referring to Table 2 (under 30- to 39-year-old males), note that this value (42.12) falls between the range of 40 and 47. This indicates that his level of aerobic fitness would be considered average. (Elite male endurance athletes such as cross-country runners and skiers have recorded oxygen consumption values as high as the upper 70s and low 80s.)

Table 1 is only valid for determining oxygen consumption when running 1.5 miles between 8 minutes and 15 minutes 55 seconds. The American College of Sports Medicine (ACSM) offers the following formula to determine oxygen consumption for running speeds of at least 5 mph [134 meters per minute (m/min)] on a level surface:

oxygen consumption = (speed in m/min) x (0.2 ml/kg/min per m/min) + 3.5 ml/kg/min

Using this formula, oxygen consumption can be estimated for a run of any known distance and duration.[1] As an example, you can estimate the oxygen consumption for

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Table 1

Predicted Values of Oxygen Consumption Based on the Time to Complete a 1.5-Mile Run

Time	Value*	Time	Value	Time	Value	Time	Value
8:00	63.84	10:00	51.77	12:00	43.73	14:00	37.98
8:05	63.22	10:05	51.37	12:05	43.45	14:05	37.77
8:10	62.21	10:10	50.98	12:10	43.17	14:10	37.57
8:15	62.01	10:15	50.59	12:15	42.90	14:15	37.37
8:20	61.42	10:20	50.21	12:20	42.64	14:20	37.18
8:25	60.85	10:25	49.84	12:25	42.38	14:25	36.98
8:30	60.29	10:30	49.47	12:30	42.12	14:30	36.79
8:35	59.74	10:35	49.11	12:35	41.86	14:35	36.60
8:40	59.20	10:40	48.75	12:40	41.61	14:40	36.41
8:45	58.67	10:45	48.40	12:45	41.36	14:45	36.23
8:50	58.15	10:50	48.06	12:50	41.11	14:50	36.04
8:55	57.63	10:55	47.72	12:55	40.87	14:55	35.86
9:00	57.13	11:00	47.38	13:00	40.63	15:00	35.68
9:05	56.64	11:05	47.05	13:05	40.39	15:05	35.50
9:10	56.16	11:10	46.73	13:10	40.16	15:10	35.33
9:15	55.68	11:15	46.41	13:15	39.93	15:15	35.15
9:20	55.21	11:20	46.09	13:20	39.70	15:20	34.98
9:25	54.76	11:25	45.78	13:25	39.48	15:25	34.81
9:30	54.31	11:30	45.47	13:30	39.26	15:30	34.64
9:35	53.87	11:35	45.17	13:35	39.04	15:35	34.48
9:40	53.43	11:40	44.87	13:40	38.82	15:40	34.31
9:45	53.01	11:45	44.58	13:45	38.61	15:45	34.15
9:50	52.59	11:50	44.29	13:50	38.39	15:50	33.99
9:55	52.18	11:55	44.01	13:55	38.19	15:55	33.83

* ml/kg/min

Haile Gebrselassie of Ethopia when he ran 10,000 meters in a world-record time of 26:31.32 in 1997. First, convert his running time (26:31.32) to its decimal equivalent. In this case, the decimal equivalent of 26:31.32 is 26.522 (31.32 seconds divided by 60 sec/min is 0.522 + 26 min = 26.522). His running speed was approximately 377.05 m/min (10,000 m divided by 26.522 min). Next, multiply his speed (377.05 m/min) by the oxygen cost of horizontal running (0.2 ml/kg/min per m/min) and add the oxygen cost at rest (3.5 ml/kg/min). This calculation yields a value of 78.91 ml/kg/min (377.05 m/min x 0.2 ml/kg/min per m/min + 3.5 ml/kg/min = 78.91 ml/kg/min).

A similar formula is used to determine oxygen consumption for walking speeds between 1.9 and 3.7 mph.[1] At lower speeds, walking is generally a more efficient process than running. In fact, the oxygen cost of horizontal walking at a given speed is about one-half that for running. Therefore, the only difference in the previously mentioned formula is that the walking speed is multiplied by 0.1 ml/kg/min per m/min (the oxygen cost of horizontal walking) and then added to 3.5 ml/kg/min (the oxygen cost at rest). So, a person who walked 2,700 meters in 30 minutes would have an oxygen consumption of 12.5 ml/kg/min (90 m/min x 0.1 ml/kg/min per m/min + 3.5 ml/kg/min = 12.5 ml/kg/min). (Note: To convert mph to m/min, multiply the mph by 26.8; to convert miles to meters, multiply the number of miles by 1,609.)

Oxygen consumption: Relative

Oxygen consumption can also be expressed in relative terms of liters per minute (L/min). Determining oxygen consumption in relative terms is usually a better indicator of aerobic fitness because the value takes into account differences in bodyweight. For instance, if two people ran the same distance in the same time, they would consume the same amount of oxygen per unit of bodyweight in absolute terms. In relative terms, however, a larger individual would actually consume more oxygen than a smaller individual because a greater body mass was displaced over a given distance.

To determine oxygen consumption in L/min, bodyweight must first be converted to kilograms (kg). To do this, divide bodyweight in pounds by 2.2. Suppose that the 35-year-old male in the earlier example weighed 198 pounds. His bodyweight would be equal to 90 kilograms (198 lb divided by 2.2 lb/kg = 90 kg). Next, multiply his bodyweight (in kilograms) by his oxygen consumption (in ml/kg/min) and divide by 1,000 (to convert to liters). His bodyweight (90 kg) multiplied by his oxygen consumption (42.12 ml/kg/min) is 3,790.8 ml/min. To divide by 1,000, simply move the decimal point three places to the left. This means that a 198-pound individual who ran 1.5 miles in 12:30 would consume about 3.79 liters of oxygen during every minute of his run.

Table 3 lists norms for oxygen consumption in relative terms based on age, gender and bodyweight.[2,6] Referring to this table (again under 30- to 39-year-old males), you'll find

Table 2

Norms for Oxygen Consumption in Absolute Terms (ml/kg/min)*

Age	Low	Fair	Average	Good	High
Women					
20–29	<28	29–34	35–43	44–48	49+
30–39	<27	28–33	34–41	42–47	48+
40–49	<25	26–31	32–40	41–45	46+
50–65	<21	22–28	29–36	37–41	42+
Men					
20–29	<38	39–43	44–51	52–56	57+
30–39	<34	35–39	40–47	48–51	52+
40–49	<30	31–35	36–43	44–47	48+
50–59	<25	26–31	32–39	40–43	44+
60–69	<21	22–26	27–35	36–39	40+

* From Astrand, 1960, and Vanderburgh & Considine, 1995.

Table 3

Norms for Oxygen Consumption in Relative Terms (L/min)*

Age	Low	Fair	Average	Good	High
Women					
20–29	<1.69	1.70–1.99	2.00–2.49	2.50–2.79	2.80+
30–39	<1.59	1.60–1.89	1.90–2.39	2.40–2.69	2.70+
40–49	<1.49	1.50–1.79	1.80–2.29	2.30–2.59	2.60+
50–65	<1.29	1.30–1.59	1.60–2.09	2.10–2.39	2.40+
Men					
Age	Low	Fair	Average	Good	High
20–29	<2.79	2.80–3.09	3.10–3.69	3.70–3.99	4.00+
30–39	<2.49	2.50–2.79	2.80–3.39	3.40–3.69	3.70+
40–49	<2.19	2.20–2.49	2.50–3.09	3.10–3.39	3.40+
50–59	<1.89	1.90–2.19	2.20–2.79	2.80–3.09	3.10+
60–69	<1.59	1.60–1.89	1.90–2.49	2.50–2.79	2.80+

* From Astrand, 1960, and Vanderburgh & Considine, 1995.

that this value (3.79 L/min) is considered to be a high level of fitness for males of his age relative to his bodyweight. Recall that when his bodyweight wasn't considered, his level of aerobic fitness was considered "average." As such, oxygen consumption gives a truer indication of fitness level when it is expressed relative to bodyweight. (Values of more than 5 or 6 L/min are fairly common in highly fit individuals.)

Expected oxygen consumption

According to the ACSM, the following regression equations can be used to predict the expected oxygen consumption of an individual based upon activity level, age and gender:

Active men:	**69.7 – (0.612 x age)**
Active women:	**42.9 – (0.312 x age)**
Sedentary men:	**57.8 – (0.445 x age)**
Sedentary women:	**42.3 – (0.356 x age)**

For example, a sedentary 40-year-old woman would be expected to have an oxygen consumption of about 28.06 ml/kg/min (42.3 minus the value of 0.356 x 40). Comparing the expected oxygen consumption to the actual oxygen consumption is helpful in determining whether a person has any functional aerobic impairment (FAI). The FAI may be found by subtracting the actual oxygen consumption from the expected oxygen consumption. This value is divided by the expected oxygen consumption and then multiplied by 100 (to convert to a percentage). If the 40-year-old woman in this example was found to have an actual oxygen consumption of 22.45 ml/kg/min, she would have an FAI of about 20 percent (the expected oxygen consumption of 28.06 ml/kg/min minus the actual oxygen consumption of 22.45 ml/kg/min divided by the expected oxygen consumption of 28.06 ml/kg/min times 100 equals 19.99 percent). A negative percentage indicates that the person's actual oxygen consumption is better than expected. Again, it should be noted that heredity plays an important role in determining a person's level of aerobic fitness.

Estimating caloric expenditure

The caloric equivalent of one liter of oxygen ranges from 4.7 calories when fats are used as the sole source of energy to 5 calories when carbohydrates are used as the only source of energy. (The caloric equivalent of one liter of oxygen is 4.4 calories when proteins are used as the single source of energy. Under most circumstances, however, protein utilization during exercise is negligible in terms of energy production and is usually disregarded.) For all practical purposes — with little loss in precision — a person uses about 5 calories for every liter of oxygen that is consumed.[5] To determine the rate of caloric expenditure, simply take the oxygen consumption value in L/min and multiply it by 5 calories per liter (cal/L). Recall the earlier example of the 198-pound male whose oxygen consumption was 3.79 L/min. In this case, his rate of caloric expenditure would be almost 19 calories per minute (3.79 L/min x 5 cal/L = 18.95 cal/min).

To determine the total number of calories that were used during the run, multiply the rate of caloric expenditure (in cal/min) by the running time. In this case, multiplying 18.95 cal/min by 12.5 minutes (12:30 in decimal form) indicates that he used about 237 calories during his run (18.95 cal/min x 12.5 min = 237 cal). **FM**

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