Preliminary Communication

A Means of Assessing Maximal Oxygen Intake

Correlation Between Field and Treadmill Testing

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One hundred and fifteen US Air Force male officers and airmen were evaluated on a 12-minute field performance test and on a treadmill maximal-oxygen-consumption test. The correlation of the field-test data with the laboratory-determined oxygen-consumption data was 0.897. The significance of this relationship makes it possible to estimate with considerable accuracy the maximal oxygen consumption from only the results of the 12-minute performance test. This test is readily adaptable to large groups, requires minimum equipment, and appears to be a better indicator of cardiovascular fitness than the more commonly accepted 600-yard run. Because of the high correlation with maximal oxygen consumption, it can be assumed that the 12-minute field performance test is an objective measure of physical fitness reflecting the cardiovascular status of an individual.

When assessing fitness for prolonged physical activity, one must expose the subject to continuous hard work in order to test him accurately. This procedure is required primarily because the easier the work, the smaller and less regular are the differences between the fit and the unfit.[1] Many tests have been suggested for assessing physical fitness including breath-holding,[2] step testing,[3-5] cycle testing,[6] treadmill testing,[1,5,7,8] and field testing.[9,10] Most of the previously mentioned tests depend upon recovery heart rates after vigorous exercise as the method for evaluating fitness although a few monitor maximal oxygen intake or performance or both. Rasch and Wilson[11] compared several laboratory tests of physical fitness with military endurance; two tests dependent upon recovery heart rates, a treadmill test[1] and a step test,[6] correlated poorly with both the 3-mile run and the 3-mile run with pack; and only the Balke treadmill test[7] showed a marked relationship with the 3-mile run with or without the pack. The Balke test uses the duration of the test in minutes and the work done in kilogram-meters per minute as criteria of physical performance. He has shown also that a linear function change in oxygen consumption occurs with time. Others have concluded that oxygen consumption during exhausting work is not only the best single physiological indicator of the capacity of a man for sustaining hard muscular work, but it is also the most objective method by which one can determine the physical fitness of an individual as reflected by his cardiovascular system.[5,8,12]

See also pages 189 and 193.

The maximal oxygen consumption or intake (maximum Vo_2) is a laboratory measurement determined most frequently during exhausting work on either a motor-driven treadmill or a bicycle ergometer. Treadmill testing is preferred because specific muscle development and extensive training are prerequisites to the achievement of maximum performance on a bicycle ergometer.[12,13] Once determined, the maximum $\dot{V}o_2$ can be expressed in liters per minute (liters/min), milliliters per kilogram of total body weight per minute (ml/kg/min), or milliliters per kilogram of lean body mass per minute (ml/kg LBM/min). Although the last is preferred, it is technically difficult to accomplish and maximal oxygen intake usually is expressed in ml/kg/min.[14]

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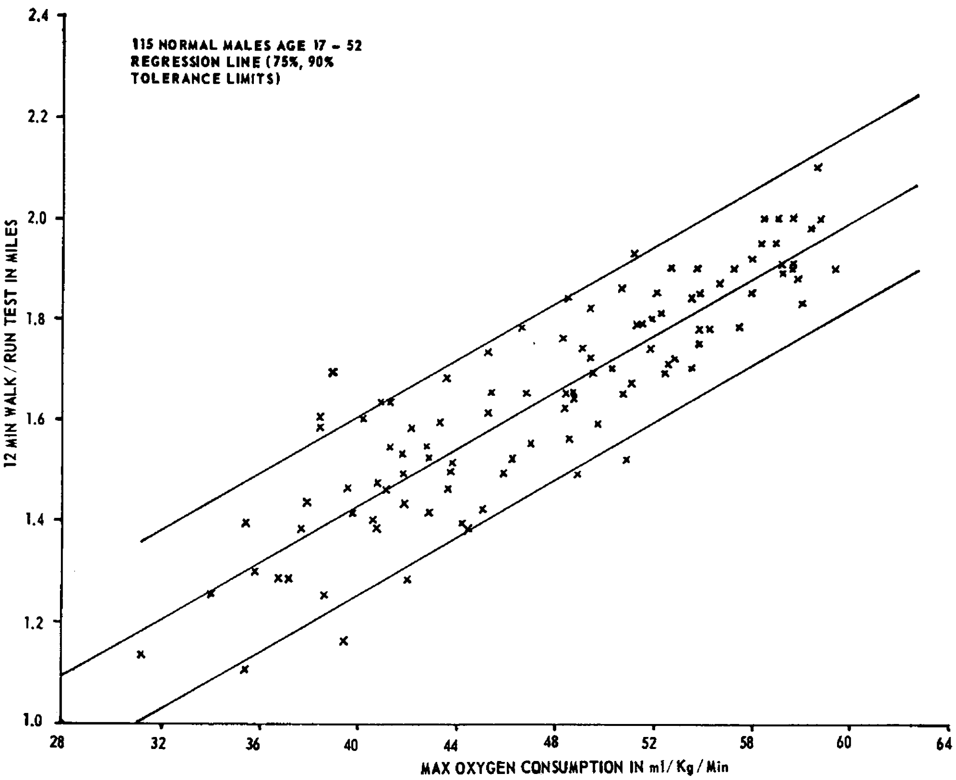

Correlation between maximal oxygen consumption and 12-minute walk-run performance in normal males. Within tolerance limits one is 75% confident that at least 95% of true maximal oxygen consumption can be found.

Inasmuch as laboratory determination of maximum $\dot{V}O_2$ is impractical for large groups, notable efforts have been made to develop a field test of fitness that correlates well with laboratory tests. One such attempt has been made by Balke[9] in which he suggests the use of various walk-run tests relating oxygen consumption either to distance covered in a given time period or to time required to run a given distance. The purpose of this paper is to present a modification of the Balke field test of fitness and to compare it with laboratory-determined maximum $\dot{V}O_2$.

Methods

In this study, 115 US Air Force male officers and airmen were asked to run a 12-minute performance test and then submit to a treadmill maximal-oxygen-consumption test. Their average age was 22 years (range, 17 to 52 years), average height, 69.7 inches (range, 64.0 to 77.5 inches), and average weight, 168 lb (range, 114 to 270 lb).

The 12-minute performance test was accomplished first on all subjects using a flat, accurately measured 1.0 mile, hard-surface course. The subjects, dressed in the appropriate running attire, were not evaluated sooner than two hours postprandially. Each subject ran the 12-minute test at least twice, and the oxygen-consumption data were compared with the nearest 12-minute test; the interval between the 12-minute test and the treadmill evaluation was no longer than three days. All subjects were instructed to cover the longest possible distance in 12 minutes, running preferably but walking whenever necessary to prevent becoming excessively exhausted. The temperature during testing ranged from 54 to 74 F (12 to 23 C) with an average of 64 F (18 C); the humidity ranged from 54% to 93% with an average of 75%; and all subjects tolerated the test without difficulty.

In order to determine maximal oxygen consumption, a treadmill test was designed to incorporate the method described by Taylor et al[8] and Mitchell et al.[5] Before starting the treadmill, the subject was connected by means of a Hans-Rudolph low resistance valve to either a balanced Tissot gasometer or a 200-liter Douglas bag.

Each test consisted of several three-minute runs separated by ten-minute rest periods. Following the guidance of Mitchell et al,[5] the objective was to reach a point at which the oxygen consumption ceased to increase or began to drop, ie, a "supermax." This method was used to determine that a true maximum $\dot{V}O_2$ had been attained. The subjects were started at 4 miles/hr on a 4% grade up to 6 miles/hr on a 6% grade according to the initial level of fitness of the subject. After his initial run, the speed was increased by half or 1 mile/hr and the grade by 0.5% or 1%. An attempt was made to exhaust all subjects with three or four three-minute runs. The maximum speed for well-conditioned subjects was 9 miles/hr at a 9% grade. Expired air was collected during each of the last two minutes of the three-minute runs. This collection period differed slightly from the time intervals used by other investigators.[1,5] All expired air was measured by a Tissot gasometer, corrected to standard temperature pressure dry and aliquots were analyzed in an E-2 paramagnetic oxygen analyzer and an infrared carbon dioxide analyzer. Frequent cross checks were made by the micro-Scholander technique. Then oxygen consumption and other respiratory indexes were determined by standard methods. Heart rate during exercise was monitored by the technique of Cooper,[15] counting R-R intervals (interval between R waves on electrocardiogram) during the final 15 seconds of each minute.

Results

For the purpose of analysis, the regression of distance in 12 minutes was plotted against oxygen consumption (Figure) rather than the reverse because of the important role of motivation in field testing. Oxygen consumption can be obtained accurately in the laboratory under more carefully controlled conditions since it is affected less by the motivational component. The correlation coefficient for this data is 0.897, which indicates a highly significant relationship, and the regression equation is walk-run distance = 0.3138 + 0.0278 O_2 with σ^2 = 0.00985, df = 113. From this regression line, a good estimate of maximal oxygen consumption can be made on the basis of 12-minute performance (Table 1).

As a result of the motivational component, the data show more variability at distances less than 1.40 miles and less variability at longer distances. Nevertheless, separate analysis of the data, excluding subjects who did not exceed 1.40 miles in 12 minutes, did not alter appreciably the slope of the regression line.

Surprisingly, repeated testing had little, if any, training effect on 12-minute performance. Several of the better motivated subjects were retested at three- to four-day intervals, and the results were highly comparable.

Bigbee and Doolittle (written communication, Feb 15, 1967) used the 12-minute test in evaluating 149 male junior high school students at Luther Burbank Junior High School, Burbank, Calif. The students were evaluated twice at four-day intervals, and the coefficient of reliability between the test and the retest was 0.976. Nine of these subjects selected at random were tested on a 600-yard run also and maximal oxygen consumption was determined later on a bicycle ergometer. Validity determinations made by use of the Spearman rho equation revealed the following:

Rank maximum $\dot{V}O_2$ to rank 12-minute run performance = 0.90; rank maximum $\dot{V}O_2$ to rank 600-yard run performance = 0.62; and rank 600-yard run performance to rank 12-minute performance = 0.83.

After a period of training, several of the original 115 subjects were reevaluated on the 12-minute and treadmill tests. It was apparent that with the training the subjects rapidly progressed up the regression line, whereas when regular exercise ceased, performance decreased but still followed the regression line.

Since the majority of the subjects tested were less than 25 years of age, it is difficult to predict the accuracy of this test in an older age group. However, preliminary indications are that the response of subjects up to at least age 50 compares favorably with the younger group.

As a result of this study, levels of cardiovascular fitness have been established for the 12-minute walk-run test (Table 2). These levels constitute a slight modification of the performance ratings suggested by Balke.[9,16]

Table 1.—Predicted Maximal Oxygen Consumption on the Basis of 12-Minute Performance

Distance (Miles)	Laps (¼ Mile Track)	Maximal Oxygen Consumption (ml/kg/min)
<1.0	<4	<25.0*
1.000	4	25.0*
1.030	...	26.0*
1.065	4¼	27.0*
1.090	...	28.2
1.125	4½	29.0
1.150	...	30.2
1.187	4¾	31.6
1.220	...	32.8
1.250	5	33.8
1.280	...	34.8
1.317	5¼	36.2
1.340	...	37.0
1.375	5½	38.2
1.400	...	39.2
1.437	5¾	40.4
1.470	...	41.6
1.500	6	42.6
1.530	...	43.8
1.565	6¼	45.0
1.590	...	46.0
1.625	6½	47.2
1.650	...	48.0
1.687	6¾	49.2
1.720	...	50.2
1.750	7	51.6
1.780	...	52.6
1.817	7¼	53.8
1.840	...	54.8
1.875	7½	56.0
1.900	...	57.0
1.937	7¾	58.2
1.970	...	59.2
2.000	8	60.2

*Insufficient data at these distances to make reliable comparisons.

Table 2.—Levels of Cardiovascular Fitness Based on 12-Minute Performance and Maximal Oxygen Consumption

Distance (Miles)	Maximal Oxygen Consumption (ml/kg/min)	Fitness Level
<1.0	<25.0	Very poor
1.0 to 1.24	25.0 - 33.7	Poor
1.25 to 1.49	33.8 - 42.5	Fair
1.50 to 1.74	42.6 - 51.5	Good
1.75 or more	51.6 or more	Excellent

Comment

The recent emphasis on cardiovascular fitness has made a good test for measuring such fitness mandatory. Maximal oxygen consumption as determined in the laboratory continues to be the best indicator of cardiovascular fitness. However, the expense, time, and personnel requirements will continue to make this procedure prohibitive for testing large groups. This study indicates that in young, well-motivated subjects, field testing can provide a good assessment of maximal oxygen consumption, but the accuracy of the estimate is related directly to the motivation of the subjects. The advantages of a test of this type are that it uses a well-known type of exercise, ie, walking and running; it costs nothing to perform; large groups can be run together; and trained personnel are not required. The only items of equipment required are an accurately measured track, a stop watch, and a horn or whistle for indicating the end of the 12 minutes. The test has been performed on a large number of subjects without problems in various types of climatic conditions. It has been used both as an indication of cardiovascular fitness and as a method of monitoring changes in fitness.

Al Rahe, Department of Biometrics, USAF School of Aerospace Medicine, Brooks Air Force Base, Tex, was responsible for the statistical analysis.

References

1. Johnson, R.E.; Brouha, L.; and Darling, R.C.: A Test of Physical Fitness for Strenuous Exertion, *Rev Canad Biol* **1**:491-504 (June) 1942.

2. Montoye, H.J.: Breath-Holding As Measure of Physical Fitness, *Res Quart* **22**:356-376 (Oct) 1951.

3. Brouha, L.; Graybiel, A.; and Heath, C.W.: Step Test: Simple Method of Measuring Physical Fitness for Hard Muscular Work in Adult Man, *Rev Canad Biol* **2**:86-91 (Feb) 1943.

4. Kasch, F.W., et al: A Step Test for Inducing Maximal Work, *J Assoc Phys Ment Rehab* **19**:84-86 (May-June) 1965.

5. Mitchell, H.; Sproule, B.J.; and Chapman, C.B.: The Physiological Meaning of the Maximal Oxygen Intake Test, *J Clin Invest* **37**:538-547 (April) 1958.

6. Astrand, P.O., and Rhyming, I.: Nomogram for Calculation of Aerobic Capacity (Physical Fitness) From Pulse Rates During Submaximal Work, *J Appl Physiol* **7**:218-221 (Sept) 1954.

7. Balke, B.: *Correlation of Static and Physical Endurance I. A Test of Physical Performance Based on the Cardiovascular and Respiratory Responses to Gradually Increased Work*, Report No. 1, Project No. 21-32-004, Randolph Air Force Base, Tex: USAF School of Aviation Medicine, April 1952.

8. Taylor, H.L.; Buskirk, E.; and Henschel, A.: Maximal Oxygen Intake As an Objective Measure of Cardio-respiratory Performance, *J Appl Physiol* **8**:73-80 (July) 1955.

9. Balke, B.: *A Simple Field Test for the Assessment of Physical Fitness*, CARI Report 63-18, Oklahoma City: Civil Aeromedical Research Institute, Federal Aviation Agency, September 1963.

10. Cooper, K.H.: Flying Status Insurance, *Aerospace Safety* **22**:8-10 (March) 1966.

11. Rasch, P.J., and Wilson, I.D.: The Correlation of Selected Laboratory Tests of Physical Fitness With Military Endurance, *Milit Med* **129**:256-258 (March) 1964.

12. Newton, J.L.: The Assessment of Maximal Oxygen Intake, *J Sport Med* **3**:164-169 (June-Sept) 1963.

13. Astrand, P.O., and Saltin, B.: Maximal Oxygen Uptake and Heart Rate in Various Types of Muscular Activity, *J Appl Physiol* **16**:977-981 (Nov) 1961.

14. Buskirk, E., and Taylor, H.L.: Maximal Oxygen Intake and Its Relation to Body Composition, With Special Reference to Chronic Physical Activity and Obesity, *J Appl Physiol* **11**:72-78 (July) 1957.

15. Cooper, K.H.: *A Simple Inexpensive Way to Monitor Electrocardiograms on an Actively Exercising Subject*, SAM-TDR-64-38, Brooks Air Force Base, Tex: USAF School of Aerospace Medicine, August 1964.

16. Balke, B., and Ware, R.W.: An Experimental Study of Physical Fitness of Air Force Personnel, *US Armed Forces Med J* **10**:675-688 (June) 1959.

IS ALCOHOLISM REALLY AN ILLNESS?—There is still debate over this question, but the preponderance of evidence points to the conclusion that alcoholism is an illness. The American Medical Association and the World Health Organization, as well as many other professional groups, have come to regard it as a specific disease entity. Some have even made official pronouncements that designate it as such, in order to stimulate interest and focus effort. Recent court decisions recognizing it *legally* as a "disease" have lent additional support to this position and in so doing have shifted the brunt of responsibility for the care of an impressive number of alcoholics away from law enforcement agencies and more appropriately onto the medical profession, and health and rehabilitation groups.

Some authorities continue to consider alcoholism as essentially a *manifestation* of underlying psychopathology. Certainly it can be seen at times as primarily a *complication* to other conditions, both physical and mental. It has also been described as basically a *symptom*, which increases and eventually attains such magnitude as to become an illness.

For practical purposes, however, and in view of evidence presently available, it seems most logically classified as a highly *complex illness*, and it will be regarded and referred to as such in this manual. . . .

Alcoholics are treatable patients. Because their illness is a chronic disorder with tendency toward relapse, it should be approached in much the same manner as are other chronic and relapsing medical conditions. The aim of treatment is then viewed more as one of *control* than cure. Abstinence is sought as a primary objective, but additional considerations, such as improved social or occupational adjustments may be far better guides in evaluating the success or failure of a treatment effort. Temporary relapse with return to drinking, then, should not be equated with failure, any more than should the diabetic's occasional discontinuation of his diet or his insulin.

The goal of every program should be to help the alcohol-dependent patient learn to deal effectively with his life problems without using the drug and to adapt to his environment in a reasonably mature manner. At the same time, effort should be made to prevent or correct the complications of his illness. Treatment centers which have utilized this approach have achieved quite remarkable success in the management of many alcoholic patients. There seems to be no good reason why these results cannot be duplicated by others, including individual physicians.—*Manual on Alcoholism*, Chicago: American Medical Association, 1967, pp 5, 8-9.

