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A SIMPLE FIELD TEST  
FOR THE ASSESSMENT  
OF PHYSICAL FITNESS

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OKLAHOMA CITY, OKLAHOMA

APRIL 1963

<p>Civil Aeromedical Research Institute, Federal Aviation Agency, Oklahoma City, Oklahoma. CARI Report 63-6. A SIMPLE FIELD TEST FOR THE ASSESSMENT OF PHYSICAL FITNESS by Bruno Balke, April 1963.</p> <p>An essential factor in air safety is the physical and mental fitness of all personnel directly involved in operations of general, commercial, and military aviation. Standardization and classification of fitness, however, have not been established to a degree which would allow for much more than a differentiation between "normal" health and pathological disturbances. Testing a large population — important for the establishment of standards — requires test procedures of simple design but capable of rendering results which are comparable to those of more complex and time consuming laboratory tests. Experiments have indicated that a 15-minute best-effort run can be utilized as substitute for a standard work capacity test in the laboratory. This type of test constitutes a satisfactory assessment of the potentially available functional reserves.</p>	<p>1. Physical Fitness Test 2. Aerobic-anaerobic Work Capacity 3. Oxygen Requirements 4. Fitness Classification</p>	<p>Civil Aeromedical Research Institute, Federal Aviation Agency, Oklahoma City, Oklahoma. CARI Report 63-6. A SIMPLE FIELD TEST FOR THE ASSESSMENT OF PHYSICAL FITNESS by Bruno Balke, April 1963.</p> <p>An essential factor in air safety is the physical and mental fitness of all personnel directly involved in operations of general, commercial, and military aviation. Standardization and classification of fitness, however, have not been established to a degree which would allow for much more than a differentiation between "normal" health and pathological disturbances. Testing a large population — important for the establishment of standards — requires test procedures of simple design but capable of rendering results which are comparable to those of more complex and time consuming laboratory tests. Experiments have indicated that a 15-minute best-effort run can be utilized as substitute for a standard work capacity test in the laboratory. This type of test constitutes a satisfactory assessment of the potentially available functional reserves.</p>	<p>1. Physical Fitness Test 2. Aerobic-anaerobic Work Capacity 3. Oxygen Requirements 4. Fitness Classification</p>
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OF PHYSICAL FITNESS**

**Bruno Balke, M. D.**

*Chief, Biodynamics Branch*

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## A SIMPLE FIELD TEST FOR THE ASSESSMENT OF PHYSICAL FITNESS

BRUNO BALKE, M. D.

### ABSTRACT

An essential factor in air safety is the physical and mental fitness of all personnel directly involved in operations of general, commercial, and military aviation. Standardization and classification of fitness, however, have not been established to a degree which would allow for much more than a differentiation between "normal" health and pathological disturbances. Much scientific work is in progress, however, to contrive, within the wide area of "normal" health, meaningful categories of physical fitness according to physiological criteria. Testing a large population — important for the establishment of standards — requires test procedures of simple design but capable of rendering results which are comparable to those of more complex and time consuming laboratory tests. The experimental work reported here is considered a minute contribution to the eventual establishment of physical fitness standards which might become helpful for acquiring and maintaining optimum work efficiency. The experiments indicated that a 15-minute best-effort run can be utilized as substitute for a standard work capacity test in the laboratory. Any objection about the adequacy of running as a proper measure of an aviator's or air traffic controller's fitness should certainly be outweighed by the recognition of the fact that this type of test constitutes a satisfactory assessment of the potentially available functional reserves.

Procedures for determining human working capacity in the laboratory take advantage of such equipment as treadmills, bicycle ergometers, or stepping devices for providing desirable and reproducible levels of work intensity. The laboratory conditions allow for a continuous monitoring of the circulatory and respiratory responses to exercise which is essential for the recognition of an individual's capacity for coordinating a complexity of organic functions. Without "on-the-spot" measurements, most tests involving physical exertion are too dependent on the individual's motivation and tolerance for pain and discomfort. Without physiological measurements *during* a "fitness" test an investigator can rarely ascertain if the subject is performing within or beyond his physiological limitations. However, situations arise which require a screening of the physical condition of a large number of people within a relatively short time. Then, laboratory testing

becomes inadequate because of restrictions in facilities, equipment, and personnel. In addition, some people might be interested in checking their own potential capacity for functional adaptability if they knew a simple procedure for obtaining such information. Therefore, a "field test" is desired which can be expected to render physiologically meaningful results. A field test of physical competence should engage a familiar type of physical exercise, involving large muscle groups and eliciting general functional responses within and up to the limits of capacity. The test accomplishments should be measurable in commonly understandable terms and readily convertible into data of physiological significance.

The type of exercise which comes very close to fulfilling most of these requirements is the work of walking and running. According to Henry's<sup>(1)</sup> compilation of data on the oxygen requirements for these exercises, level walking

at a fast pace produces metabolic rates up to eight times the resting value, while in relatively slow running the energy expenditure may exceed the resting rate as much as 10 times or more. This explains why most "normal" people usually become quickly exhausted when "in a hurry": 70 to 80 per cent of an adult male population attain cardio-respiratory limitation at energy expenditures of 10-11 Mets (Mets = multiples of the basal metabolic rates).<sup>(9)</sup>

On the other hand, the possibility for altering metabolic rates deliberately within the range of functional competence by either going faster or slower makes running and/or walking an ideal test activity. The test subject, asked to run a given distance or a given length of time, has only to adjust his pace for optimum performance. The most critical factor for obtaining an optimum pace and useful test results appears to be the distance or the length of time an individual has to run: if too short, most of the work will be done in oxygen debt; if too long, fatigue and slipping motivation will affect the test results. A sufficient time interval is essential, permitting either a steady pace at the functional crest load or an alternating pace, in which the aerobic component, when running too fast, is compensated for by adequate recovery in slowing down.

In some of our studies on the physiological effects of physical conditioning the observation was made that the improvements in physical working capacity not only became apparent in treadmill or bicycle ergometer performance, but also in the performance of running two or three miles. The correlation between these performances was so close that a prediction of either one appeared possible after the other had been established. Experimental efforts were made, therefore, to investigate these correlations in more detail and to establish the procedure of a running test for the evaluation of "physical fitness" under field conditions.

## PROCEDURES AND METHODS

1. The oxygen requirements for running at different velocities were determined on a horizontal treadmill. The male subjects used in this study were accustomed to running as a non-competitive exercise for physical conditioning. Measurements of the respiratory gas

exchange were made during the third, fifth, and seventh minute of each run in order to determine the steady state values for oxygen intake. Whenever, in these investigations, the oxygen intake ceased to increase with higher running velocity, the value of  $\dot{V}_{O_2}$  obtained was not utilized for establishing the aerobic requirements of running.

2. At the end of a 10-week training period, in which most of the physical conditioning consisted in running and walking, work capacity of eight male subjects was determined on the treadmill, using the procedure of gradually increasing work as previously described.<sup>(9)</sup> Then, each individual ran for the duration of 1, 5, 12, 20, and 30 minutes on different days, attempting to cover the greatest possible distance in each run. For each of these runs the average velocity was calculated and, in turn, expressed in the physiological term of oxygen requirement. The latter was compared with the value for maximum oxygen intake obtained in the treadmill test with the purpose of establishing the closest correlation between running and treadmill performance.

3. In the previous experimental series a comparison of treadmill against running performances was made in trained subjects. In this series nine other adult males, untrained and of sedentary living habits, served as subjects in similar testing procedures, first on the treadmill and then in a two mile run. The average velocity in the latter run was, again, expressed in amounts of oxygen required per unit of time and compared with the maximum oxygen intake determined in the treadmill test.

4. The same procedure was employed in a study of 34 high school boys, with the exception that the duration for the running test was set at 15 minutes and the boys were asked to do their best in trying for the greatest distance within that time.

In all running tests the subjects started separately and spaced at certain time intervals. They were told to start relatively slowly and to settle, after two or three minutes, into a pace they thought suitable for covering the entire distance. They were also told to slow down or to walk in case of serious muscular or respiratory disturbances but to resume running at a faster pace after sufficient recovery.

## RESULTS

1. Figure 1 presents the results of the first series of experiments designed to establish the relationship between running velocities and their energy costs expressed in oxygen requirements. Although the relatively few experiments reported in the literature and the compilation of their data by Henry<sup>(1)</sup> suggest that this relationship follows a curvi-linear pattern (see Fig. 2) there was evidence, from experiments carried out by Åstrand<sup>(2)</sup> with high school boys, that the amounts of oxygen required for velocities between 133 m/min. (5 m.p.h.) and about 290 m/min. (11 m.p.h.) were linearly related to the running performances. Our results, obtained from five adult male subjects (see Fig. 1), were practically identical with those obtained by Åstrand (see Fig. 2). This identity of results encouraged the use of these established curves as a base for the estimation of oxygen requirements for all the running velocities determined in the following investigations.

2. The experiments designed to establish the duration or length of a run which may yield a

performance criterion equivalent to that obtained in an accepted treadmill test are summarized in Table 1. Age, body weight, and maximum oxygen intake of the eight subjects are presented in addition to the average velocities attained in the five runs of different duration. A comparison of the estimated oxygen expenditures for these runs with the maximum oxygen intake capacity established on the treadmill revealed that the treadmill results could be matched with the results obtained in runs of approximately 10 to 20 minutes duration. Only in runs of such a duration did the individuals settle down to an average pace which reflected most closely their aerobic work capacity. During one minute of running, as the figures show, a major portion of work was done anaerobically, and even in a 5-minute run a great part of the performance was accomplished in oxygen debt. Running longer than 20 minutes, on the other hand, resulted in a performance inferior to that on the treadmill, averaging about 9 per cent below the maximum capacity for oxygen intake.

SUBJ.	AGE YEARS	WEIGHT kg
● B	50	74.0
+ C	38	68.5
x E	50	73.5
△ G	35	67.5
○ H	26	82.5

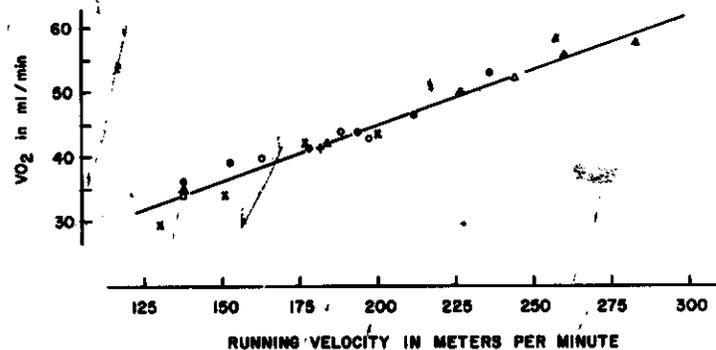


FIGURE 1: Oxygen intakes during "steady state" running on a treadmill at various velocities.

TABLE I

Subj.	Age years	Weight kg	TREADMILL		RUNNING					
			Max. $\dot{V}_{O_2}$ ml/kg/min	1 min $\dot{V}_{O_2}$ ml/kg	5 min $\dot{V}_{O_2}$ ml/kg	12 min $\dot{V}_{O_2}$ ml/kg	20 min $\dot{V}_{O_2}$ ml/kg	30 min $\dot{V}_{O_2}$ ml/kg		
B	50	76.3	49.2	369	260	224	209	192	43.3	
C	41	88.5	48.7	407	262	206	200	191	43.0	
D	35	85.3	37.3	264	180	163	—	136	34.0	
G	34	70.0	52.9	407	315	282	250	238	51.0	
H	22	82.7	46.3	343	—	215	200	202	45.0	
R	35	88.4	41.3	332	236	204	183	171	40.0	
E.T.	28	85.4	46.2	367	240	204	180	169	39.5	
W.T.	36	85.0	47.0	343	250	204	190	180	41.2	
Av.			46.1	70.5	52.6	46.7	43.8	42.0		

Oxygen requirements ( $\dot{V}_{O_2}$ ) for running velocities (V) were estimated from the experimentally established curve presented in Figure 1. An extension of the straight line was used for an approximate estimation of the oxygen requirements beyond the velocity of 300 m/min.

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3. In this experimental series, the maximum oxygen intake (in ml/kg/min) attained by nine sedentary individuals during the treadmill test was correlated with the oxygen consumption estimated from the average velocity during a 2-mile run. The results are plotted in Fig. 3: In seven out of nine subjects the performance criteria for both tests checked within a range of  $\pm 5$  per cent, and only in two subjects was the running performance about 7 per cent lower than the treadmill performance. On the average, both tests rendered practically the same results when expressed in terms of peak oxygen uptake.

4. The group of 34 high school boys had an average maximal oxygen intake of 43.6 ml/kg/min in the treadmill test. Asked to run 15 minutes on an oval track and to cover the greatest possible distance during that time, the boys averaged a velocity which required an oxygen intake of 44.4 ml/kg/min. The individual data are plotted in Fig. 4. Most boys

stayed well within the acceptable range of  $\pm 10$  per cent deviation from the perfect correlation. A few boys performed better in the running test than was predictable from the objective treadmill data. An explanation of this rather unexpected phenomenon will be attempted in the following discussion.

## DISCUSSION

The state of physical fitness can be assessed by determining an individual's potential capacity for high energy demands or, more simply said, by determining his working capacity. Total work capacity is made up of two phases: the aerobic phase, in which the oxygen supply to the working tissue covers adequately the requirements, and the anaerobic phase, in which oxygen requirements exceeding the aerobic capacity are met by the body's ability to incur a certain amount of oxygen debt. Aerobic conditions prevail for all work intensities below the level of "crest load" although, because of a

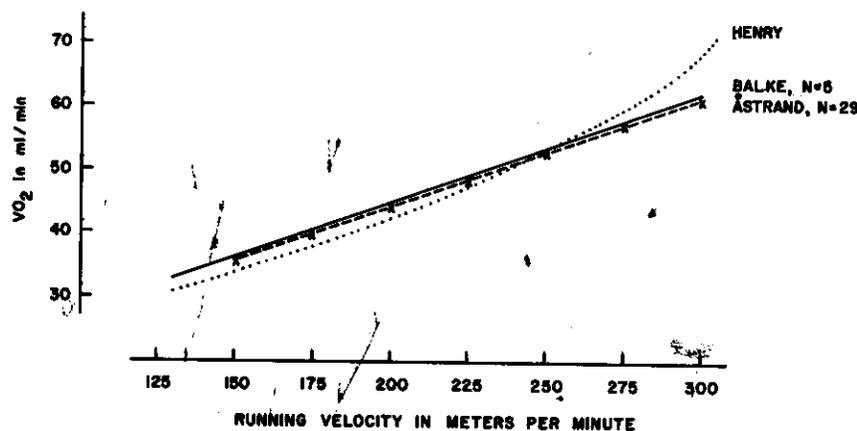


FIGURE 2: Oxygen requirements for running, as determined by various investigators; data compiled by Henry<sup>(1)</sup>, dealing with total oxygen intakes for velocities given in feet per second, were converted into  $\dot{V}_o$  in ml/kg/min for velocities in meters per minute by assuming an average body weight of 70 kg for all the experimental subjects involved.

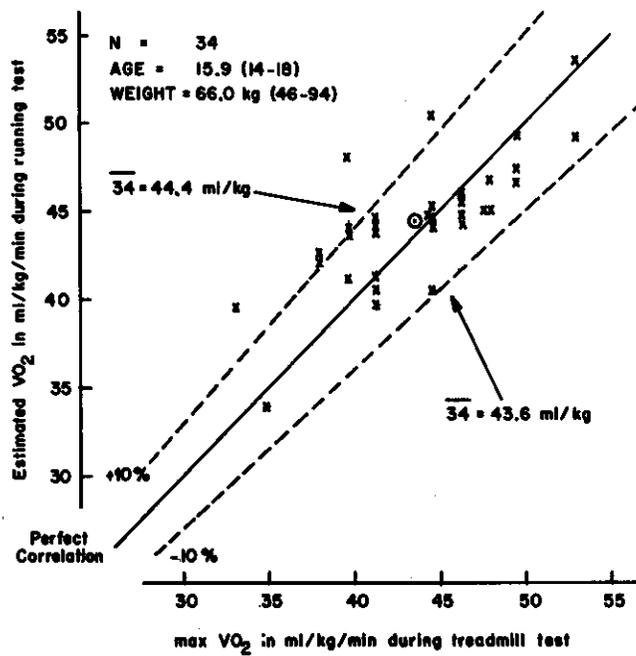


FIGURE 3: Values of maximum intake attained in treadmill tests were correlated with values of  $\dot{V}O_2$  estimated for the average velocities attained in a two-mile run.

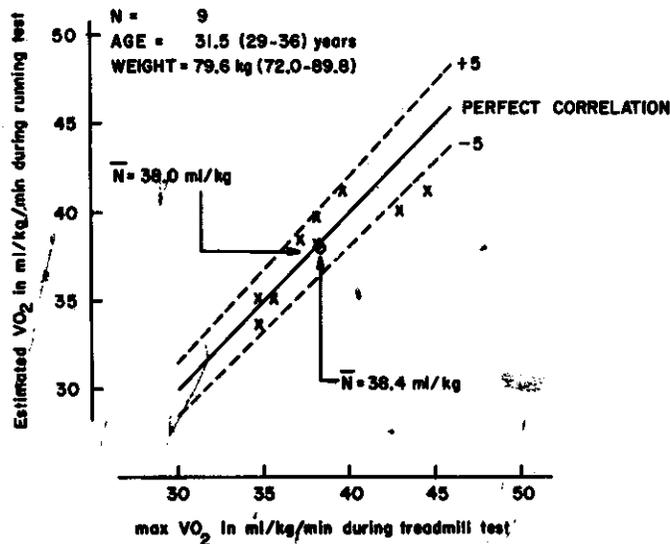


FIGURE 4: Values of "maximum"  $\dot{V}O_2$  estimated from treadmill performance, were correlated with values of  $\dot{V}O_2$  estimated for the average velocities attained in a best-effort run of 15 minutes duration.

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time lag in proper functional adjustments, a certain amount of oxygen debt is carried along through the entire working period. The cardio-respiratory adjustments require time periods of 1 to several minutes, the so-called "warm-up" time. In work, beginning at the level of crest load or with an over-load, proper functional adjustments do not catch up with the demands and, in time, incapacitating symptoms of dyspnea and/or muscular inadequacy force termination of work. The duration of work, in such a case, depends on the individual's ability to tolerate the accompanying pains and discomforts which become more and more intensified with growing oxygen debts.

These considerations of the aerobic and anaerobic phases of work capacity are quite essential for the establishment of a useful field test of physical fitness. In Fig. 5 an attempt is made to illustrate the role of the oxygen debt capacity for the performance of exercises requiring near all-out efforts for time intervals from 1 to 15 minutes. It can readily be seen that a very short effort, e.g., running 100 yards in 10 seconds, is accomplished almost entirely anaerobically; during a four-minute run the oxygen debt capacity covers about 20 per cent; during an 8-minute effort still about 10 per cent of the total oxygen requirements. However, in work periods exceeding 12 to 15 minutes,

the anaerobic phase becomes less and less important for the accomplishment of the total work, accounting for not more than about 5 per cent of the totally required amounts of oxygen.

Since only the assessment of the aerobic work capacity is useful as a realistic measure of the potentially available functional reserves, the duration of a physiologically meaningful field test should be at least 12 minutes. The experimental results of the reported investigations practically confirmed the validity of these more theoretical considerations: namely, the best agreement between the objective criterion of work capacity, obtained in a complex laboratory test, and the comparable criterion estimated from a field test liable to be affected by subjective factors was found when the duration of the running test was between 12 to 20 minutes. One would expect that the running performance should be slightly inferior to the treadmill performance: the normal man, almost entirely deprived of the privilege and opportunity to use his very own mile-eating tools, is inclined to hold back in unfamiliar exerting efforts extended over a relatively long period of time. Amazingly, in the experiments reported here, the expected differences in test results were negligible despite the fact that in many cases the motivation for the running tests was rather low. Contrary to expectation,

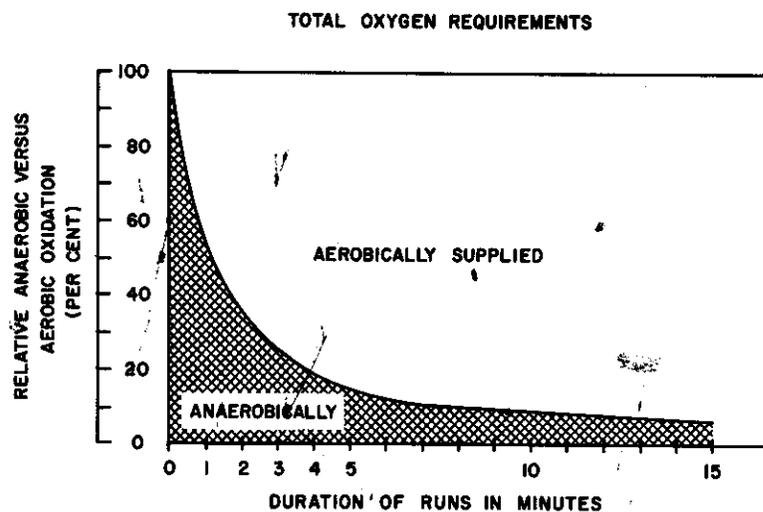


FIGURE 5: The relative role of anaerobic and aerobic oxidation for supplying the total amounts of oxygen required during best-effort runs of defined time intervals. These total oxygen requirements were calculated for actual running performances of an individual having a  $\dot{V}_{O_2}$  maximum of 3.6 l/min and an oxygen debt capacity of 3 liters.

there were a few cases in which the actual running performance exceeded considerably the performance predictable from the treadmill results. The explanation of this discrepancy is rather simple: the routine treadmill test is usually halted when the subjects attain heart rates of 180 to 190 per minute. Most people reach the peak of aerobic work capacity around such heart frequencies and the termination of work at this point prevents undesirable over-stressing of the subjects. However, beside individuals who have definite limitations of work capacity at lower heart rates — and those are readily picked up in the treadmill tests and pose no problem in the running — there are many, especially in the younger age brackets, who can still work aerobically at heart rates of 200 per minute and more. These subjects, in a running test on their own, set their pace according to their subjective sensation and judgment. In performing better than expected they display more realistically the potentially available cardio-respiratory and otherwise important functional reserves.

Rating the performances — as suggested in a previous report<sup>(3)</sup> — as poor, average or fair, good, very good, and excellent according to maximum oxygen intake capacities of 30-35, 35-40, 40-45, 45-50, and 50-55 ml of oxygen per kg per minute, respectively, 70 per cent of all the subjects utilized in this study achieved the same classification in both the treadmill and the running test, 10 per cent rated one level lower, but 20 per cent one level higher in the running test.

Approximately 1500 more individuals, most of them Federal Aviation Agency employees, have been subjected to the 15-minute running test during the last two years with satisfying results. The test was also recommended to people who wanted to evaluate their state of physical fitness and its changes due to training, alterations in weight, disease, and other factors.

## SUMMARY

1. Within the range of aerobic work capacity a practically linear relationship exists between running velocities and oxygen requirements per unit of body mass.

2. The maximum oxygen intake attainable — the most adequate criterion of work capacity — was determined in a standardized treadmill test and then compared with the oxygen requirements estimated for average velocities achieved in best effort runs over various distances. The performances in runs of 12 to 20 minutes duration, expressed in amounts of required oxygen, matched the objectively measured aerobic capacity most closely.

3. Based on these findings, a field test for the assessment of physical fitness was established which employs a 15-minute run — around or along known distances — at best individual efforts. From the accurate distance and time measurements the average velocity in meters per minutes was determined and converted into the physiologically meaningful value of equivalent oxygen requirement. In a "best effort" this value represents very closely the aerobic work capacity and permits a rather objective rating of physical fitness.

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