WALK OR JOG FOR HEALTH: II*

ESTIMATING THE MAXIMUM AEROBIC CAPACITY FOR EXERCISE

C. H. WYNDHAM, N. B. STRYDOM, C. H. VAN GRAAN, A. J. VAN RENSBURG, G. G. ROGERS, J. S. GREYSON AND W. H. VAN DER WALT, *Human Sciences Laboratory, Chamber of Mines of South Africa, Johannesburg*

It is essential for the medical practitioner who is advising a patient upon a programme of exercises to improve his physical condition, to be able to estimate the patient's maximum aerobic capacity for exercise. With this information, and a knowledge of the energy costs of walking and jogging at different speeds, he can advise the patient of the speeds at which he can walk or jog safely.

The physiologist measures the individual's maximum aerobic capacity for exercise in terms of his maximum oxygen intake. The direct measurement of maximum oxygen intake in the laboratory is time-consuming and costly. It requires a treadmill or bicycle ergometer and the staff and equipment for the accurate measurement of the individual's oxygen consumption at a number of work loads up to the individual's maximum physical effort. There has, in consequence, been a search for simpler and shorter methods, preferably using submaximum work loads, which will give reliable estimates of the maximum oxygen intake. One such method is the submaximum step test which is based upon the linear relationships between heart rate and oxygen consumption when measured at a number of different submaximum work loads.[1] Comparisons between maximum oxygen intakes estimated by the submaximum step test and those measured directly on a treadmill and a bicycle ergometer have been published by this laboratory.[2]

However, even the step test of maximum oxygen intake requires equipment for the accurate measurement of heart rates and oxygen consumptions at a number of submaximum work loads and, therefore, the employment of skilled technical staff. There is clearly the need for an even simpler test of maximum oxygen intake which requires neither special equipment nor trained technical staff. Cooper's 12-minute walk or run procedure for predicting the maximum oxygen intake appears to fulfil these requirements.[3] All that is needed is a stop-watch and a level 440-yard track so that the distance which the individual can walk or run in 12 minutes can be measured accurately. Cooper showed that there was a correlation coefficient of 0·897 between maximum oxygen intake measured directly on the treadmill and the distance run. The study was made on 115 volunteers from the US Air Force who were between 17 and 52 years of age and weighed between 51 and 130 kg (114 and 270 lb).

Cooper's procedure for predicting the maximum oxygen intake has much to commend it for the medical practitioner who wishes to estimate a patient's maximum aerobic capacity for physical conditioning and to follow his progress during the programme. However, before we could recommend this test we considered it to be essential to validate Cooper's predictions from the 12-minute run against direct measurements of maximum oxygen intake on the treadmill on a random selection of White South African males living in Johannesburg. It was possible that living at Johannesburg's medium altitude of 1 763 m (5 748 ft) above sea-level might upset the close correlation shown by Cooper. Accordingly, maximum oxygen intakes were measured on the treadmill on a sample of 25 volunteers from the laboratory staff. The subjects then ran as far as possible in 12 minutes on a level running track. The volunteers were aged between 17 and 54 years and weighed between 60 and 110 kg (132 and 242 lb). The direct measurements of maximum oxygen intake were then compared with the predictions from Cooper's regression equations.

The 12-minute run requires a high degree of motivation which might not always be present in the individual to be tested. The step-test procedure, being based upon measurements of heart rate and oxygen consumption at a number of submaximum work loads, is independent of motivation. Also, being a submaximum effort test, it is more suitable, and safer, for individuals with cardiorespiratory disability or those in their late 50s and early 60s. It was therefore also decided to determine the maximum oxygen intakes of 24 of the subjects by means of the step-test procedure. For this purpose heart rates and oxygen consumptions were measured at work levels of 54 and 81 W (2 400 and 3 600 ft-lb/min). (The mean oxygen consumptions for these work rates were 1·38 and 1·83 litres/min respectively.) The maximum oxygen intake estimated from the heart rate and oxygen consumption at these submaximum work loads is compared with those of the 12-minute run and the direct measurement on the treadmill.

*Date received: 13 October 1970.

TABLE I. BASIC DATA ON TREADMILL, STEP TEST AND 12-MINUTE RUN

				Treadmill												Stepping at 54 W (2400 ft-lb/min)		Stepping at 81 W (3600 ft-lb/min)		Distance run in 12 min	
				O_2 intake (litres/min)																	
Subject	Height (cm)	Weight (kg)	Age (years)	Rest	3 mph (4·8 km/h)	4 mph (6·4 km/h)	5 mph (8·1 km/h)	6 mph (9·7 km/h)	7 mph (11·3 km/h)	8 mph (12·9 km/h)	9 mph (14·5 km/h)	10 mph (16·1 km/h)	11 mph (17·7 km/h)	12 mph (19·3 km/h)	Maximum heart rates (beats/min)	O_2 consumption (litres/min)	Heart rates (beats/min)	O_2 consumption (litres/min)	Heart rates (beats/min)	Miles	Kilometres
1	176·8	90·60	54	0·3630	1·2977	1·6950	2·5926	3·0979	3·1346	3·5323	3.4404	—	—	—	175	1·5410	101	1·8785	120	1·50	2·4
2	178·1	72·58	46	0·3183	0·9313	1·3764	1·9774	2·4301	2·7221	2·9903	3·2143	3·1886	3·2532	—	152	1·2378	96	1·5338	111	1·73	2·8
3	183·0	78·80	33	0·3084	0·9343	1·2456	2·1111	2·6487	2·7748	3·0765	3·1663	3·1578	3·3266	—	177	1·3317	93	1·7233	118	1·65	2·6
4	182·6	110·58	31	0·4788	1·3843	2·0769	3·3602	3·6607	3·8561	3·8368	—	—	—	—	198	1·5976	140	2·1755	158	1·29	2·1
5	183·4	76·88	40	0·2562	0·9174	1·4666	2·2818	2·5454	2·6691	2·7496	—	—	—	—	188	1·2176	114	1·6995	137	1·30	2·1
6	181·4	85·95	44	0·3116	0·9963	1·4544	2·5356	2·8663	2·8156	3·0567	2·9016	—	—	—	189	1·5706	152	1·9945	170	1·22	2·0
7	178·2	82·78	31	0·3867	1·0676	1·5016	2·3198	2·7918	3·0372	3·1466	3·0852	—	—	—	185	1·4624	123	1·8017	140	1·45	2·3
8	180·9	70·80	28	0·3337	0·9559	1·3309	2·1679	2·4918	2·6023	2·8584	3·0859	3·2571	3·2619	—	185	1·3489	108	1·7502	124	1·73	2·8
9	175·2	76·58	34	0·2952	0·8777	1·4423	2·1634	2·5821	2·6111	2·7186	2·8865	3·2178	—	—	188	1·3303	119	1·7161	149	1·51	2·4
10	176·6	60·95	32	0·3240	0·8369	1·1915	2·0263	2·3719	2·4875	2·6667	2·6351	2·6941	—	—	192	1·2084	121	1·7530	155	1·55	2·5
11	176·8	63·08	32	0·3151	0·9047	1.3533	2·1560	2·4518	2·6139	2·8230	2·9374	2·9123	—	—	186	1·3790	144	1·8212	156	1·61	2·6
12	178·5	65·83	25	0·3172	1·0218	1·4149	2·3652	2·5710	2·6154	2·7863	3·0201	3·0421	3·0046	—	194	1·2088	111	1·6360	136	1·56	2·5
13	181·9	70·58	24	0·2590	1·0026	1·2890	2·2182	2·5814	2·7366	2·9753	3·3902	3·6096	3·6414	—	191	1·2282	113	1·8337	133	1·72	2·8
14	177·2	75·18	27	0·3000	0·9687	1·4136	2·4891	2·8311	2·8846	3·0969	3·1233	3·3101	3·2398	—	184	1·4185	117	1·8180	135	1·68	2·7
15	172.2	85·85	24	0·3658	1·4138	2·0952	2.3439	—	—	—	—	—	—	—	202	1·6557	194	2·0683	205	1·00	1·6
16	172·3	69·58	32	0·3227	0·9252	1·3680	2·1688	2·5680	2·8228	3·2052	3·3401	3·4802	3·5130	—	186	1·1953	97	1·5752	112	1·81	2·9
17	175·7	111·70	32	0·3946	1·3094	2.0940	3·0694	3·0829	3·4774	3·4941	—	—	—	—	172	1·6849	109	2·0234	116	1·20	1·9
18	172·3	61·70	27	0·3298	0·9324	1·1928	1·9067	2·1380	2·3831	2·6467	2·9779	3·3708	3·5353	3·3665	192	1·2338	108	1·6193	122	1·84	3·0
19	188·6	102·90	24	0·4758	1·5012	2·0828	3·5559	4·1285	4·2086	4·5333	4·4887	—	—	—	189	1·7431	138	1·9725	142	1·50	2·4
20	176·2	76·10	23	0·3923	1·0836	1·4891	2·3713	2·7903	2·9310	3·1793	3·2592	3·5065	—	—	195	1·4075	122	1·7839	139	1·73	2·8
21	177·6	75·20	21	0·3658	1·0437	1·5236	2·8119	3·0273	3·2168	3·1994	3·4635	3·4477	—	—	184	1·3868	122	1·7684	133	1·62	2·6
22	192·2	84·60	20	0·3821	1·1374	1·4175	2·8058	3·2771	3·2019	3·6762	3·9579	4·2256	4·3839	4·5041	195	1·2940	133	1·8999	145	1·71	2·8
23	181·0	72·25	22	0·3120	0·9635	1·4585	2·2645	2·8520	2·7369	3·1708	3·5016	3·8924	4·0113	4·0415	184	1·4754	114	1·8759	127	1·80	2·9
24	190·2	69·08	21	0·3359	0·9384	1·2637	2·0916	2·6208	2·7840	3·0246	2·9273	2·9468	—	—	190	1·3598	147	1·7751	175	1·62	2·6
25	178·0	64·45	17	—	—	—	—	—	—	—	4·0373	4·2532	4·3086	—	—	—	—	—	—	2·30	3·7

METHOD

Maximum oxygen intake was determined on the laboratory's treadmill by the method that has been discussed in detail in a previous publication.[2]

In brief the subjects walked on the treadmill, on the flat, at speeds of 4·8, 6·4 and 8·1 km/h (3, 4 and 5 mph) and ran at 9·7 km/h (6 mph) for 10-minute periods. Above 9·7 km/h (6 mph) the period of running was reduced to 5 minutes. Between each bout of exercise the subjects rested for approximately 15 minutes. The speed of running was increased by 1·6 km/h (1 mph) steps until a speed was reached at which the individual could not complete a period of 5 minutes of exercise.

Oxygen consumption was determined by collecting expired air in a Douglas bag through special low-resistance valves over a period of 3 minutes up to 9·7 km/h (6 mph) and over a period of 1 minute at higher speeds. The concentration of oxygen in an aliquot sample of expired air was measured in a Beckman paramagnetic oxygen analyser. Heart rates were monitored by means of an ECG with special chest electrodes.

RESULTS

The heights, weights and ages of the 25 subjects are given in Table I. The table also includes the oxygen consumptions measured at the different speeds of walking or running on the treadmill and the maximum heart rates attained, the heart rates and oxygen consumptions when stepping at 54 and 81 W (2 400 and 3 600 ft-lb/min) and the distances run in 12 minutes.

The maximum oxygen intakes in ml/kg body-weight per minute when *(i)* measured directly on the treadmill; *(ii)* predicted from the 12-minute run from Cooper's regression equation; and *(iii)* estimated from the step test, are given in Table II.

The correlation coefficient between maximum oxygen intakes, predicted from the 12-minute run and those

TABLE II. ESTIMATES OF $Vo_{2MAX.}$ ON TREADMILL, 12-MINUTE RUN AND STEP TEST

Subjects	$Vo_{2MAX.}$ *(treadmill)*	$Vo_{2MAX.}$ *(12-min run)*	$Vo_{2MAX.}$ *(step test)*
1	39·2	42·6	36·0
2	44·3	50·8	46·0
3	40·2	48·0	35·8
4	34·8	35·4	33·8
5	35·5	35·0	35·5
6	34·6	32·0	27·5
7	38·1	41·0	33·3
8	46·0	50·5	46·6
9	40·3	43·0	30·6
10	43·6	45·0	36·8
11	46·4	46·5	45·6
12	46·0	45·0	40·8
13	51·1	50·8	49·5
14	43·3	49·0	39·6
15	27·8	25·0	24·2
16	50·5	53·6	49·6
17	31·2	32·0	31·3
18	56·0	54·8	54·0
19	43·8	42·6	42·9
20	46·1	50·5	37·7
21	47·7	47·2	47·2
22	52·5	50·0	47·5
23	55·3	53·0	49·9
24	44·3	47·2	29·2
25	66·6	69·6	—

measured directly on the treadmill was 0·94, compared with the correlation coefficient of 0·88 between the maximum oxygen intakes estimated for the step test and direct measurements on the treadmill.

However, it is not only the correlation coefficients that are important. We need to know whether there are significant differences between the means determined by these various methods and whether the differences between the determinations of the methods are constant over the range of the measurements. The first of these points is examined in Table III in which the means of the maximum oxygen intakes, determined by the various methods, are compared.

TABLE III. MEANS AND MEAN DIFFERENCES OF $Vo_{2MAX.}$

Parameter	*n*	*Mean*	*Mean difference*	*Significant at the 5% level*
Treadmill	25	44·184	−1·42	Yes
12-min run	25	45·604		
Treadmill	24	43·275	+3·654	Yes
Step test	24	39·621		

This shows that the mean for the 12-minute run is significantly higher and the mean for the step test significantly lower than the direct measurement on the treadmill. The second point was examined by determining regression equations for the maximum oxygen intakes, from the 12-minute run, on the values for the treadmill, and from estimates, from the step test, on the values for the treadmill.

Regression Equations

(a) *Legend*:

Treadmill $Vo_{2MAX.}$ = x
12-min run $Vo_{2MAX.}$ = y_1
Step test $Vo_{2MAX.}$ = y_2

(b) *Equations*:

$y_1 = 1{\cdot}016x + 0{\cdot}71$ Standard error of estimate = 3·07
$y_2 = 0{\cdot}9933x - 3{\cdot}36$ Standard error of estimate = 3·95

Regression lines from these equations are drawn in Figs. 1 and 2 together with the individual results. Fig. 1 shows that, over this range of measurements, the maximum oxygen intakes predicted from the 12-minute run are consistently higher than those measured directly on the treadmill; Fig. 2 also shows that the maximum oxygen intakes, estimated from the step test, are consistently lower than those measured on the treadmill.

The variability of the maximum oxygen intakes of different individuals about these regression lines is indicated by the errors of the estimates, and shows that the variability of the predictions for the 12-minute run is slightly less than the estimates from the step test.

DISCUSSION

It is clear from the high correlation coefficient of 0·94 between the maximum oxygen intakes predicted from Cooper's 12-minute run and the maximum oxygen intakes measured directly on the treadmill, and also from the closeness of the regression line to the line of identity for these two determinations of maximum oxygen intake, that the prediction of oxygen intake from the 12-minute run is a reasonably accurate method of estimating an individual's maximum oxygen intake. However, Cooper's test does demand a sustained physical effort for a period of 12 minutes and this may be difficult to achieve in poorly motivated individuals. Also, the 12-minute run could be dangerous for unfit, overweight individuals in their late 50s and early 60s who do not take any form of regular exercise (weekend golf or tennis does *not* qualify an individual as fit enough for an all-out 12-minute run) or ambulatory patients with some form of cardiorespiratory disability. The 12-minute run for these two categories of subjects should only be carried out after the medical practitioner has satisfied himself that it is safe to do so, and preferably after an exercise ECG has been read by a competent cardiologist.

The dangers inherent in an all-out 12-minute run can be avoided of course by the use of the step-test procedure, which has a correlation

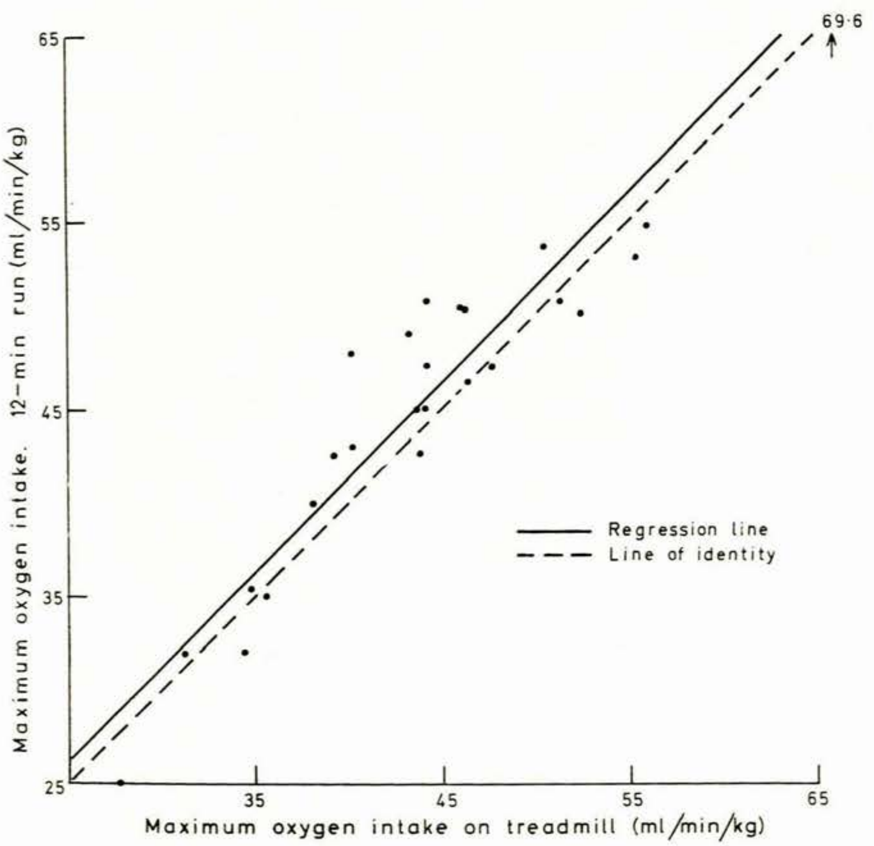

Fig. 1. $Vo_{2MAX.}$ measured during a 12-minute run plotted against $Vo_{2MAX.}$ measured on a treadmill.

coefficient of 0·88 with the direct measurements on the treadmill. The estimate of maximum oxygen intake for the step-test procedure is made from measurements of heart rate and oxygen consumption at two or more submaximum work levels. These work levels can be adjusted so that even patients with cardiorespiratory disability can carry out the task without strain. In this regard it will be noted that subject No. 15, who was grossly overweight and never took any form of physical exercise, had a heart rate of 195 beats/min while stepping at 54 W (2 400 ft-lb/min) (a mean oxygen consumption of 1·38 litres/min). Work levels of 17·5 and 35 W (780 and 1 560 ft-lb/min) would have been more reasonable for a grossly unfit individual of this nature. Some years ago the step-test procedure, using these low work levels, was used on ambulatory patients with rheumatic heart disease before and after cardiac surgery in order to evaluate the effect of the procedure upon their capacities for aerobic exercise.[4]

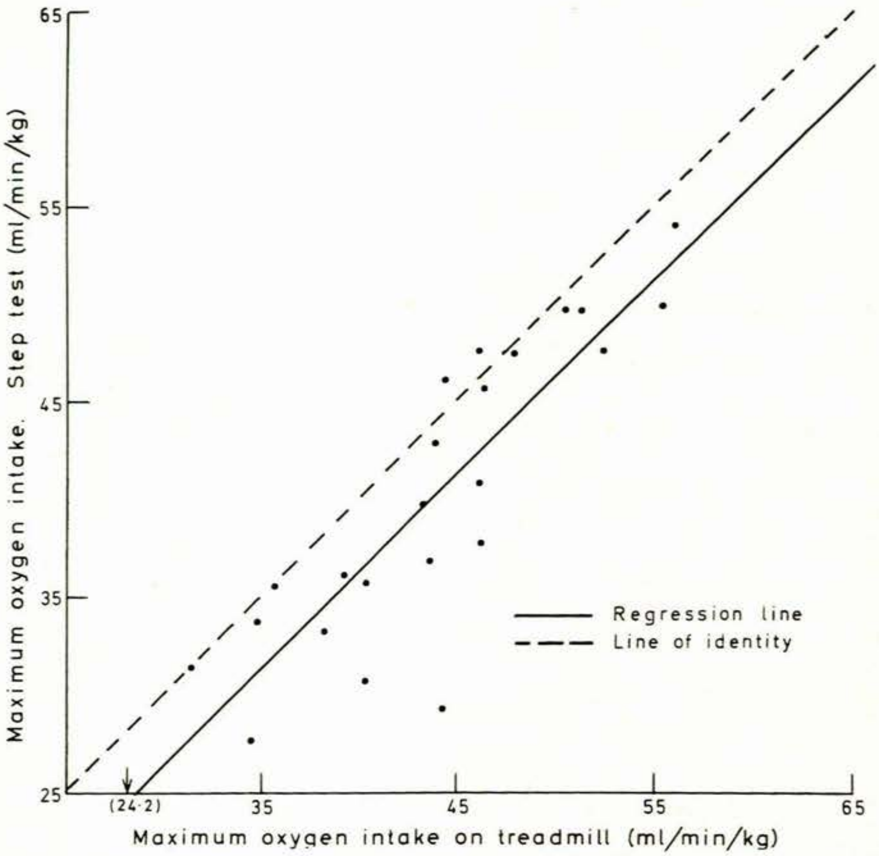

Fig. 2. $Vo_{2MAX.}$ measured during a step test plotted against $Vo_{2MAX.}$ measured on a treadmill.

The predictions of maximum oxygen intake from Cooper's regression equation from the 12-minute run are so good that there is little advantage in substituting the regression equation obtained on our subjects at Johannesburg's altitude. This point is made in Fig. 3 where Cooper's regression line and our regression line are drawn; the regression equations with their standard deviations are as follows:

(*a*) H.S.L.: Distance = $0{\cdot}0291\ O_2 + 0{\cdot}3006$ $\sigma^2 = 0{\cdot}0076$
$\sigma = 0{\cdot}0872$

(*b*) Cooper: Distance = $0{\cdot}0278\ O_2 + 0{\cdot}3138$ $\sigma^2 = 0{\cdot}00985$
$\sigma = 0{\cdot}09925$

What is surprising from Fig. 3 is that our subjects could run approximately 0·08 km further in 12 minutes at different values of maximum oxygen intake than could Cooper's subjects. This difference may be due to the fact that the direct measurement of maximum oxygen on the treadmill (which requires maximum effort) is affected more by the altitude of 1 763 m (5 748 ft) above sea-level than is the distance run in 12 minutes (which is a submaximum effort). The subjects of the present experiment were all well acclimatized to Johannesburg's medium altitude, being permanent residents in Johannesburg. Previous work from this laboratory has shown clearly that maximum oxygen intakes, measured on the treadmill, are 12% lower in Johannesburg than at sea-level.[5]

It can be concluded from these studies that the 12-minute walk or run test of Cooper can be used to assess the maximum oxygen intake of well-motivated subjects with reasonable accuracy. The next issue is the interpretation of the results. Age and sex have been shown by the Astrands[6,7] to have a major effect on maximum oxygen intake. Our proposal therefore is that for males under 30 years of age, Cooper's fitness classification be used; this is

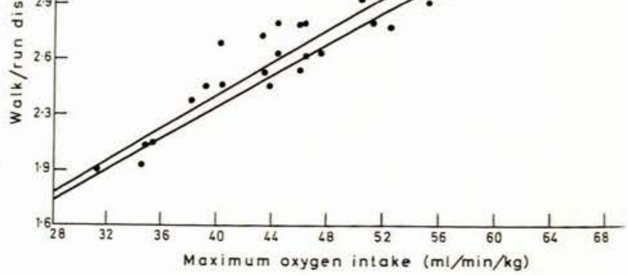

Fig. 3. Regression line (and individual plots) of walk/run distance on $Vo_{2MAX.}$ for Human Sciences Laboratory subjects and regression line for Cooper's subjects.

given in Table IV. For age-groups above 30 years, Irma Astrand's[7] adjustments can be used tentatively; i.e. maximum oxygen intake categories in Table IV are reduced by 20% for the 40 - 50 age-group and by 30% for the 50 - 60 age-group. These adjustments for age are tentative and should form the subject of future research in South Africa, as also should be the classification for females of different age-groups.

TABLE IV. COOPER'S LEVELS OF CARDIOVASCULAR FITNESS IN RELATION TO 12-MINUTE RUN AND $VO_{2MAX.}$

Distance		$VO_{2MAX.}$	*Fitness*
Miles	*Kilometres*	*(ml/min/kg)*	*level*
<1·0	<1·61	<25·0	Very poor
1·0 - 1·24	1·61 - 1·99	25·0 - 33·7	Poor
1·25 - 1·49	2·00 - 2·39	33·8 - 42·6	Fair
1·50 - 1·74	2·40 - 2·80	42·7 - 51·5	Good
1·75 or more	2·81 or more	51·6 or more	Excellent

SUMMARY

The medical practitioner who is advising a patient upon a programme of exercise must be able to estimate the patient's maximum aerobic capacity for exercise. Tests on a treadmill or bicycle ergometer are time-consuming and costly, but Cooper's 12-minute run or walk requires a level 440-yard track and a stop-watch only. Submaximal tests are safer for individuals with cardiorespiratory disability or for men aged over 50 years. Comparisons were therefore made of maximum oxygen intakes measured by means of the three procedures on 25 subjects varying in weight from 60 to 110 kg and in age from 17 to 54 years.

Predictions from Cooper's test correlated highly (0·94) and estimates for the step test correlated well (0·88) with the treadmill measurements. Cooper's test overestimates maximum oxygen intake and the step test underestimates it, but the differences are small.

Cooper's run or walk test can therefore be used safely to predict accurately the maximum oxygen intake of individuals who take regular exercise. The step test is preferable for patients with cardiorespiratory disability, or overweight, sedentary individuals in their 40s and 50s. Tentative suggestions are made for using the results to estimate cardiorespiratory fitness of individuals of different ages.

REFERENCES

1. Maritz, J. S., Morrison, J. F., Peter, J., Strydom, N. B. and Wyndham, C. H. (1961): Ergonomics, **4**, 97.
2. Wyndham, C. H., Strydom, N. B., Leary, W. P. and Williams, C. G. (1966): Int. Z. angew. Physiol., **22**, 285.
3. Cooper, K. (1968): J. Amer. Med. Assoc., **203**, 135.
4. Wyndham, C. H. and Ward, J. S. (1957): Circulation, **16**, 348.
5. Wyndham, C. H., Strydom, N.B., Benade, A.J.S. and Rogers, G. (1971): J. Appl. Physiol. (in the press).
6. Astrand, P. O. (1952): *Experimental Studies of Physical Working Capacity in Relation to Sex and Age*. Copenhagen: Munksgaard.
7. Astrand, I. (1960): Acta physiol. scand., **49**, 169.