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THE GRADATIONAL STEP TEST FOR ASSESSING CARDIORESPIRATORY CAPACITY: AN EXPERIMENTAL EVALUATION OF TREADMILL AND STEP TEST PROCEDURES

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THE GRADATIONAL STEP TEST FOR ASSESSING CARDIORESPIRATORY CAPACITY: AN EXPERIMENTAL EVALUATION OF TREADMILL AND STEP TEST PROCEDURES

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"Physical Fitness" — the potential capacity for making adequate functional adjustments to increased metabolic demands — is most meaningful and accurately assessed in the laboratory by making physiological measurements on the experimental subject while he is walking on a motor-driven treadmill or riding a stationary bicycle ergometer. For the physician in his cardiorespiratory examination room both types of equipment are too bulky. He prefers a less complicated test apparatus and uses, most commonly, a single-level or two-level stepping box as suggested by Master [1,2]. For field studies on athletes and on soldiers various other stepping devices with and without additional loading of the subjects have been suggested and utilized and the widest preference was given to the Harvard Step Test [3] performed on a bench of 20 inches in height. The disadvantage of all these stepping devices is their restriction to a fixed workload as long as the stepping rhythm is held at one constant rate. Considering the great differences of physical fitness in a large population, the fixed workload might be either adequate, or of insufficient intensity, or more or less beyond an individual's working capacity. The most useful procedures for the assessment of physical competence are those in which the cardiorespiratory adjustments are allowed to progress gradually from the resting state through various phases of increasing energy demands until the approach of limitations can objectively be determined. With a single-level or double-level stepping device such variation of work intensity requires a gradual speeding up of the stepping cadence. Such a procedure has not proven practical. In attempts to devise a testing procedure equally useful and applicable in the research laboratory as well as in the general practioner's medical examination room and also under any type of experimental field conditions, other stepping devices and methods were tried and evaluated against the standard treadmill test used in this laboratory. [4]

The 4-Box Step Test

As a simple precursor to any following multilevel stepping device a wooden box was constructed having four arbitrarily chosen platforms of 10, 20, 30 and 40 cm each (Figure 1). A stepping rate of 30 vertical lifts per minute was selected and this rhythm was audially and/or visually maintained by a metronome. Work was begun at the lowest platform and proceeded after a stepping period of 3 minutes, without interruption, to the next higher level of the box. The increments in load were continued until a) the subject fell behind the rhythm indicated by the metronome and was unable to resume the stepping rate of 30 per minute; b) when a definite decline in systolic blood pressure was observed at pulse rates to be considered maximal (usually in the vicinity of 180 beats per minute ; c) when at the end of any 3-minute period the pulse rate had reached a level of 168 beats per minute and the efforts of the subjects were

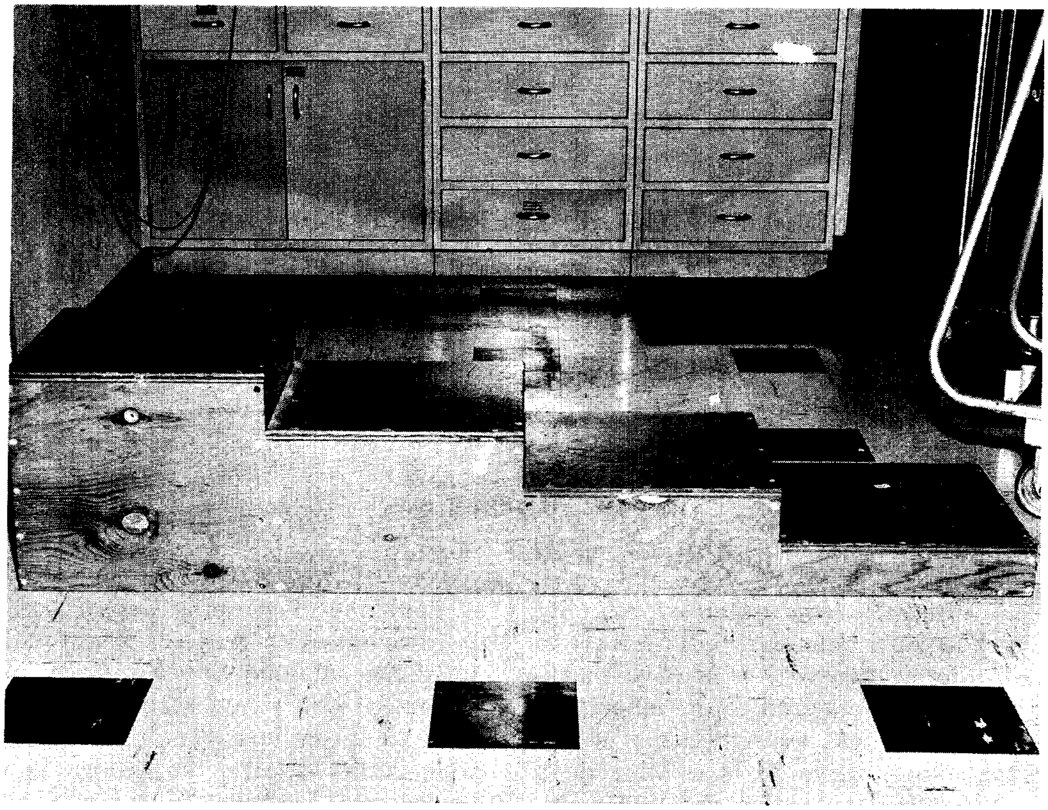

FIGURE 1: 4-Box stepping device.

indicative of approaching limitations in the ability to make the adequate adjustments needed for the next higher step. Pulse rate and blood pressure were measured in the conventional way during the second half of each minute on each platform level.

Results

Preliminary experimental data indicated that the oxygen costs of stepping to the heights of 10, 20, 30 and 40 cm approximated the energy expenditures observed in walking on the treadmill at a speed of 91.5 m/min (equal to 300 feet/min or 3.4 m.p.h.) and at grades of 3, 8, 14 and 22 per cent, respectively. Subsequently, more experiments were carried out with 12 male volunteers who were given the standard treadmill test and the 4-box step test. The oxygen intake data, presented in Table 1, confirmed the previous findings, especially for the middle

		4-Box Step Test		4-Grade Treadmill Test	
Time Min.	Subjects N	Height cm	Oxygen Intake ml/kg/min	Grade %	Oxygen Intake ml/kg/min
3rd	5	10	16.9 ± .8*	3	16.1 ± 1.2
6th	10	20	23.2 ± 2.6	8	23.1 ± 1.4
9th	10	30	31.9 ± 2.6	14	31.7 ± 1.4
12th	5	40	41.9 ± 2.1	22	44.8 ± 1.7

*Standard Deviation

TABLE 1: Oxygen intakes during the third minute of work at the progressive loads indicated. Stepping was performed at a rate of 30 per minute, walking at a velocity of 91.5 m/minute.

ranges of work intensity. A split-plot design factorial analysis was applied to the oxygen data obtained on the treadmill at the 8 and 14 per cent grade as compared to those on the 20 and 30 cm level of the stepping box; the data from the other workload levels appeared to be insufficient for inclusion. The analysis indicated that there were no significant differences in the values of oxygen intake for the two types of exercises at the work intensity levels chosen for comparison.

On the basis of the similarity in metabolic costs between these established levels of work on either the 4-step box or on the treadmill it was postulated that the final treadmill performance — which, so far, had been used for the assessment of work capacity or of "physical fitness" — might be predicted from an extrapolation of the heart rates measured at the various stepping levels on the box. On graph paper, with the per cent grade of the treadmill and the corresponding stepping height on the abscissa and with the heart rate on the ordinate, the pulse rates measured during stepping at the various levels of work were properly plotted (Figure 2). Then a line of best fit was drawn through these observed values. At the intersection with the pulse line of "180" — considered as the "critical" pulse frequency of the "average man" — the perpendicular was drawn and the potential treadmill performance was read off the abscissa. Table 2 presents the values of treadmill performance predicted from the step test versus the actually measured treadmill performance.

Subject	Treadmill Performance Actual	Treadmill Performance Predicted
1	30	29
2	27	26
3	23	25
4	24	24
5	24	21
6	16	19
7	18	17
8	17	16
9	17	15
10	16	15
11	15	12

TABLE 2: Comparison of peak treadmill performances actually achieved in a standardized *W*ork *C*apacity *T*est and of treadmill performances predicted from extrapolation of heart rate data in the 4-box step test. The figures represent the minute of the treadmill test in which the heart rate of 180 was, or would have been attained during the W.C.T. on the treadmill.

A comparison of the predicted and actual treadmill performance data yielded an $r = .94$. The regression line $y = 2.6 + .9x$ with 5 per cent error estimates is shown in Figure 3.

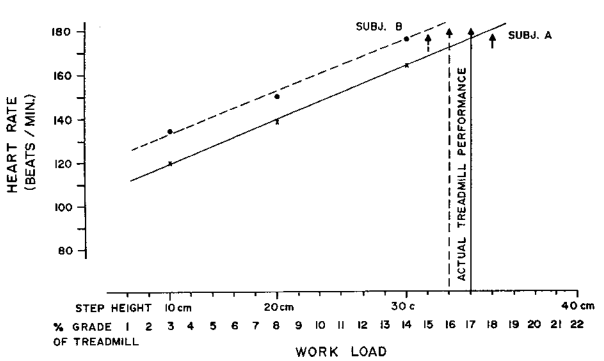

FIGURE 2: Illustration of pulse extrapolation technique for predicting the peak treadmill performance of 2 subjects from the 4-box step test.

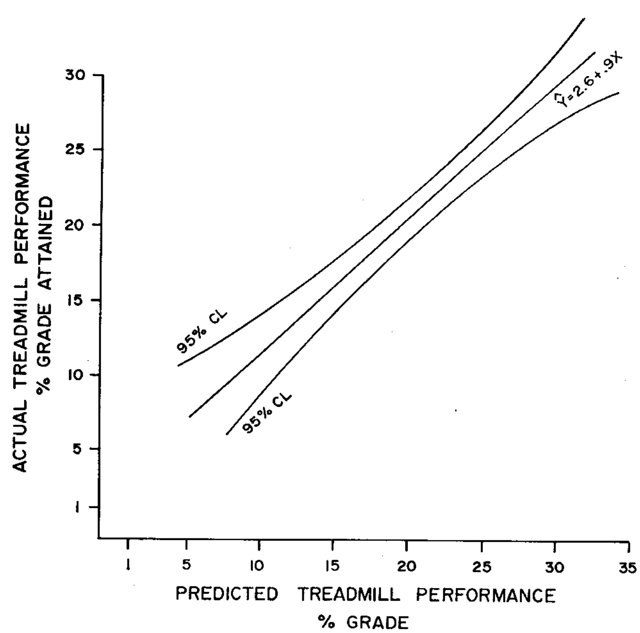

FIGURE 3: Regression line for prediction of peak treadmill performance from 4-box step test.

An Abbreviated Treadmill Test

The results and experiences with the 4-box step test encouraged us to use, parallel to the step test, an equivalent testing procedure on the treadmill especially on such days when confronted with a physical fitness evaluation of 40 to 50 subjects within 4 - 5 hours time. The work loads on the treadmill were set nearly identical to those imposed in the step test by running the treadmill belt at a constant speed of 91.5 m/min at grades of 3, 8, 14 and 22 per cent for 3 minutes each in continuous succession. As in the step test, heart rate and blood pressure were measured toward the end of each minute and the test was terminated in accordance with the criteria used in the 4-box step test.

Results

For a critical evaluation of the usefulness of such an abbreviated test of work capacity on the treadmill twelve subjects were given the standard test (gradual minute-by-minute increases of workload) and — after sufficient recovery or in reversed sequence — the abbreviated treadmill test. In both tests the respiratory gas exchange was determined at the grades of 8, 14 and 22 per cent, in the abbreviated test during the third minute on these levels. The oxygen consumption during the one-minute period on the same grade during the standard test was slighly less (See Table 3), indicating that steady state work conditions were not completely achieved. However, a statistical analysis revealed no significant differences between the oxygen intakes for equal loads due to the different exercise treatments.

Subjects N	Treadmill Grade %	Oxygen Intake, ml/kg/min W.C.T.	Abbrev. T.T.
12	8	23.6 ± 1.0	24.8 ± 1.8*
12	14	32.5 ± 1.5	33.3 ± 2.7
3	22	43.7 ± 1.5	44.3 ± 1.8

***Standard Deviation**

TABLE 3: Comparison of oxygen consumption during work on the treadmill at the same grade: in the standardized W.C.T. the loads were increased from minute-to-minute, in the abbreviated treadmill test every three minutes whereby oxygen consumption was determined during the third minute.

With the establishment of the similarity in metabolic costs anc pulse response the heart rate extrapolation technique as described previously was applied. The intersection of the line of best fit drawn through the pulse rates measured in the abbreviated test with the pulse rate line of "180" was used for the prediction of the performance to be expected in the standard treadmill test. A comparison of predicted and actually measured work capacity (See Table 4) give the latter a slight edge of 2 per cent. The

Subject	Treadmill Performance Actual	Predicted
1	30	31
2	24	24
3	20	20
4	20	19
5	20	18
6	19	18
7	15	17
8	19	16
9	17	16
10	16	16
11	15	16
12	16	15

TABLE 4: Comparison of peak treadmill performance actually achieved in a W.C.T. and that predicted from extrapolation of heart rate data in the abbreviated treadmill test. The figures represent the minute in which the heart rate of "180" was, or would have been attained during the W.C.T. on the treadmill.

correlation coefficient was r = .95. The regression line y = 1.6 + .9x with 5 per cent error estimates is shown in Figure 4.

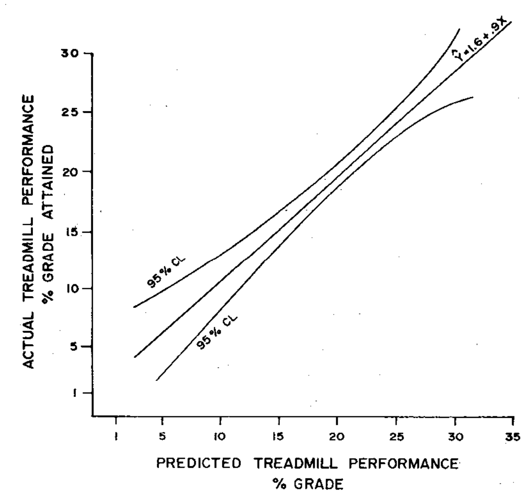

FIGURE 4: Regression line for prediction of peak treadmill performance from abbreviated treadmill test.

Gradational Step Test

The previous experimental work had shown that the 4-box step test proved useful for predicting work capacity in close agreement with that actually measured by the standard treadmill test. The observation was made, however, that the increments in load from step to step were too large. At the rate of 30 body lifts per minute many testees displayed signs of physiological limitations before progressing to the third (30 cm) stepping height. On the other hand, a reduction of the stepping rate to 24 per minute did not provide the near maximum load required for adequately testing subjects in good physical condition. Therefore, attempts were made to develop and construct a stepping device allowing for a quick adjustment of any desirable platform height up to 50 centimeters. The finally acceptable end product (See Figure 5) consisted of a platform attached to the vertical aluminum frame structure with a roller arrangement. Through the rearward base of the platform runs a jack-screw rod that, when turned either by hand (for field use) or by a small electric motor (in the laboratory) moves the platform up or down. The motor was controlled by a simple toggle switch held and activated by the investigator. The height of the platform was variable from 2.5 to 50 cm above ground and any height adjustments could be made while the subject continued stepping.

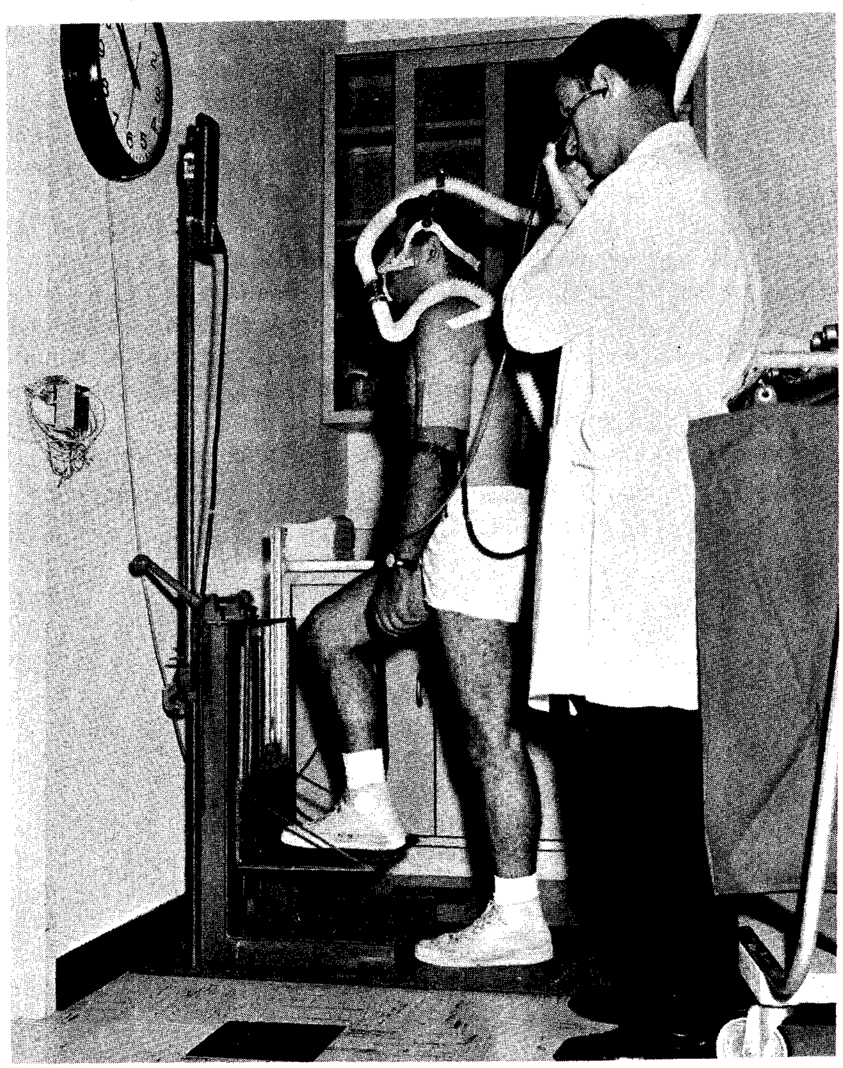

FIGURE 5: Gradational stepping device and method of measuring physiological parameters.

With this device attempts were made to develop a procedure most closely copying the energy demands of the standard treadmill test. Four test procedures were subsequently evaluated, all starting out with an initial stepping height of 8 cm. At this height the metabolic demands in stepping up and down at a rate of 30 per minute were nearly the same as during the first minute on the treadmill (at 1% grade and 91.5 m/min). The four procedures were:
Procedure I: Stepping at a rate of 24 body lifts per minute, raising the platform 2 cm at the beginning of each minute.
Procedure II: Stepping at a rate of 30 body lifts per minute and raising the platform 2.54 cm (1 inch) each minute.
Procedure III: Stepping rate of 30 but minute-by-minute increments of 2 cm in stepping height.
Procedure IV: The stepping rate was maintained at thirty and the load increments at 2 cm but the technique of stepping up and down was altered. On count "4" the foot was not returned to the ground but allowed to rest on the platform. Thus, the leg lift on count "1" of the next stepping cycle was avoided which reduced somewhat the metabolic costs of work for each level.

Procedures 1 through 3 were performed identically: the subject stepped onto the platform ("one-two") to a completely erect stance on both feet and returned ("three-four") to the ground. Subjects were encouraged to change the leading leg frequently. This was accomplished by just tapping the foot coming down on count "4" and lifting it again on count "1."

In all tests the heart rate and blood pressure were continuously monitored and the respiratory gas exchange was determined periodically and always during the peak minute. The test was terminated when the attainment of a maximum heart rate became obvious or when the pulse pressure began declining at pulse rates considered near maximum.

Results

Procedure I was quickly discarded when trained individuals in good physical condition reached the highest platform level of 50 cm without attaining cardio-respiratory and/or local muscular limitations. The test duration in this type of step test exceeded that of the standard treadmill test performed for comparison. Therefore, this procedure was judged inadequate for physical fitness screening of a normal healthy population.
Procedure II was evaluated in experiments with 2 female and 13 male volunteers. The subjects ranged from 16 to 56 years of age. All participants took the standard treadmill test and the gradational step test at two different occasions several days apart. The performance data are presented in Table 5. Calculation of a correlation coefficient for the data yielded an $r = .76$.

SUBJECT	STEP TEST PROCEDURE II		TREADMILL W.C.T.	
	Time min	Vertical Lift m/min	Time min	Vertical Lift m/min
1	6	6.2	10	9.2
2	6	6.2	10	9.2
3	6	6.2	12	11.0
4	8	7.7	12	11.0
5	10	9.3	14	12.8
6	10	9.3	14	12.8
7	10	9.3	15	13.7
8	10	9.3	16	14.6
9	11	10.0	16	14.6
10	12	10.8	16	14.6
11	12	10.8	16	14.6
12	12	10.8	22	20.1
13	12	10.8	22	20.1
14	13	11.6	16	14.6
15	14	12.6	18	16.5

TABLE 5: Peak performances in the Gradational Step Test, Procedure II, (rate "30," minute-by-minute increments of 1 inch in stepping height), and in the W.C.T. on the treadmill (in which the % grade is the same as the indicated minute). All tests were terminated at a heart rate of "180."

Body Wt. Kg.	Peak Heart Rate (beats/min) Treadmill	Step Proc. II	Peak Vo_2 (ml/min) Treadmill	Step Proc. II	Peak Vo_2: Pulse (ml/beat/min) Treadmill	Step Proc. II
52.6	180	176	1316	1112	7.3	6.3
58.0	180	180	1561	1237	8.7	6.9
86.5	182	180	2337	2185	12.8	12.1
99.2	180	182	2871	2604	16.0	14.3
77.2	184	184	2595	2312	14.1	12.6
97.2	184	180	3112	2966	16.9	16.5
77.2	182	184	2335	2223	12.8	12.1
73.9	184	184	2348	2447	12.8	13.3
71.3	184	182	2634	2394	14.3	13.2
81.4	180	180	2886	2400	16.0	13.3
65.7	180	180	2389	2375	13.3	13.2
67.2	182	180	2607	2601	14.3	14.5
74.5	182	180	2831	2561	15.6	14.2
66.3	182	180	2941	2520	16.2	14.0
74.9	182	180	3533	2840	19.4	15.8
	$\bar{X}$=182	$\bar{X}$=181	$\bar{X}$=2553	$\bar{X}$=2318	$\bar{X}$=14.0	$\bar{X}$=12.8

TABLE 6: Comparison of peak values for oxygen intake, heart rate and oxygen pulse during W.C.T. on the treadmill and Procedure II of the Gradational Step Test.

Unexpectedly, inconsistencies in performances occurred among two better trained individuals. There was also a tendency seen, in this step test, that performances were grouped in a relatively narrow range. This might indicate that the initial load and the minute-by-minute increments of work intensity were too high to delineate the finer differences in the compensatory functional capacities of individuals.

A comparison of the peak values for oxygen intake, heart rate and oxygen-pulse (Table 6), revealed nearly the same maximum pulse frequency for both types of test work but a lower peak oxygen intake for the work of stepping. The average oxygen pulse, which is the fraction of oxygen taken out of the volume of blood moved into circulation with one heart contraction, amounted to 14 ml at the peak load on the treadmill but to only 12.8 ml at the maximum level of stepping. This is of interest in so far as it shows that even for similar or related types of work the pulse rate response cannot be considered an accurate indicator of the metabolic load involved. The mean difference in oxygen pulse (ml of oxygen intake per heart beat) between the two tests proved to be significant in a paired t-test ($P < .01$).

Min.	Gradational Step Test, Procedure III Subjects N	Vo_2 ml/kg/min	Heart Rate beats/min	W.C.T. on Treadmill Subjects N	Vo_2 ml/kg/min	Heart Rate beats/min
2	28	16.7 ± 2.0*	125	22	15.2	120
4	25	19.7 ± 1.7	131	21	18.5	127
6	27	22.6 ± 2.2	146	22	21.7	136
8	28	25.9 ± 2.3	157	22	25.0	146
10	27	28.2 ± 2.5	168	22	28.3	158
12	21	31.1 ± 2.1	175	21	31.6	166
14	14	34.1 ± 2.1	180	16	34.8	171
16	10	36.6 ± 1.5	186	13	38.1	177
18	2	41.3 ± 1.4	181	9	41.3	184
20				6	44.6	186
22				2	47.9	184

*Standard Deviation

TABLE 7: Comparison of oxygen consumption and heart rate during the same minutes of the Step Test, Procedure II, and the W.C.T. on the treadmill.

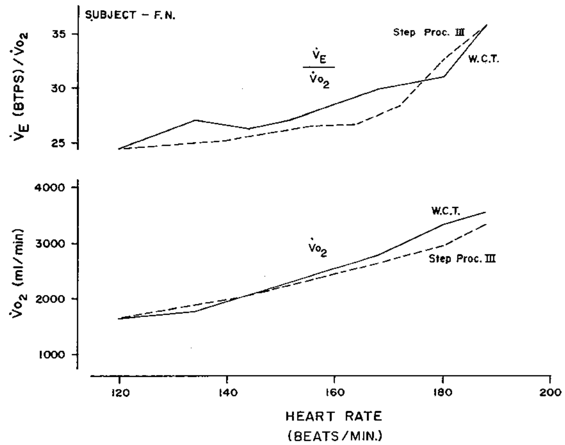

FIGURE 6: Oxygen intake and ventilation equivalent ($\dot{V}_E$: $\dot{V}O_2$) correlated with heart rate in both the Work Capacity Test on the treadmill and the Gradational Step Test Procedure III.

Procedure III. Twenty normal male adults participated in this test series and a few more performed the step test only for additional information on the metabolic costs of this procedure. The latter are depicted in Table 7 which, for comparison, also shows the average oxygen intakes of a large population for identical minutes of work in the standard treadmill test[4]. Although the oxygen requirements almost matched each other in both tests during the same intervals of work, there were differences in hemodynamic qualities at the higher workload levels which resulted in a lower peak oxygen intake at the maximum heart rate in the step test (see Figure 6). These differences may explain the shorter test durations in the step tests as compared to the treadmill test (Table 8). Calculation of a correlation coefficient yielded an r = .95.

SUBJECT	GRADATIONAL STEP TEST, PROC. III Time (min)	W.C.T. ON TREADMILL Time (min)
1	18	22
2	18	22
3	16	20
4	16	20
5	16	19
6	15	19
7	13	17
8	13	17
9	13	16
10	13	16
11	13	15
12	13	13
13	12	15
14	12	14
15	12	13
16	11	14
17	10	13
18	10	11
19	8	12
20	8	9

TABLE 8: Peak performance in the Step Test, Procedure II, (rate "30," 2 cm-step increments) and in the W.C.T. on the treadmill.

Procedure IV. With this procedure, which duplicated the former in stepping rate and graduated increments in height but differed in the rhythm of work, the test duration as well as the peak heart rate response approached the values observed in the treadmill test but the peak oxygen intake was even lower than in procedure III (see Table 9). The four participating subjects experienced about the same subjectively limiting symptoms — local muscle fatigue and severe dyspnea — in all three tests. Use of Duncan's multiple range test showed that the differences in oxygen-pulse were not significant between any two tests.

DISCUSSION

For reasons previously cited a sound *step test* procedure would have great utility to researchers and clinicians in measuring physical performance capacity. Attempts have been made to devise such a procedure based on a proven and widely used treadmill test procedure called the Balke Test[5]. Work in the test is graded from light to heavy over a time period which allows "normal" individuals to adapt, minute-by-minute, to the increasing loads, up to some maximum established by physiological limitations. The duration of the test ranges from 7 to 30 minutes, the average being 15 minutes.

Such a step test requirement precludes consideration of many procedures currently in use. The original Harvard Step Test[3] in which a single level bench 20 inches (50 cm) in height is used with a stepping rate of 30 per minute, requires maximal effort from the onset of exercise. This results in a high level of anaerobic work and prevents an accurate evaluation of aerobic capacity. Morehouse[6] states that the test is useful for selecting men for hard work and for evaluating the progress of physical training. On this basis it would not appear applicable for the performance testing of a "normal" population. The same would seem to apply to some modifications of the Harvard Step Test or similar procedures described by Gallagher and Brouha[7], Fletcher[8], Hettinger et al.[9], and the "Pack" tests used by Darling et al.[10] and Graybiel et al. [11].

	Step Procedure IV				Step Procedure III				Standard Treadmill Test			
Subj.	Step Time (min)	Max. Pulse (Beats/min)	Max. V_{O_2} ml/min	Max. V_{O_2} Pulse	Step Time (min)	Max. Pulse (Beats/min)	Max. V_{O_2} ml/min	Max. V_{O_2} Pulse	Test Time	Max. Pulse	Max. V_{O_2} ml/min	Max. V_{O_2} Pulse
1	20	184	2824	15.3	18	176	3060	17.4	22	176	3307	18.8
2	20	188	3386	18.0	18	188	3408	18.1	22	192	3675	19.1
3	17	188	2719	14.5	16	188	2865	15.2	19	188	3000	16.0
4	13	178	2283	12.8	10	178	2507	14.1	13	180	2685	14.9

TABLE 9: Comparison of heart rate, oxygen intake and oxygen pulse during the peak (final) minute of work in Step Test Procedure III and IV and in the W.C.T. on the treadmill.

Rhyming[12] modified the Harvard Step Test, selecting a 40 cm step for men (33 cm step for women) and a rate of 22.5 steps per minute. These changes allowed for a working duration of 5 minutes at sub-maximal responses. However, the procedure necessitated the use of a pulse extrapolation technique for the prediction of aerobic work capacity.

Master's Test[1] as originally described and updated[2] utilizes a 2-step bench (22.5 cm per step). The stepping rate is determined from tables based on weight and age. Work is continued for 1½ minutes, or for 3 minutes in the Double Master's Test. For satisfactory performance the subject's pulse and blood pressure must return to resting levels within 2 minutes following the cessation of exercise. Master's Test is not suitable for our purposes for three reasons: 1) his concept of an exercise tolerance (capacity) is hardly definitive. Data from Master's tables shows that for the age-weight ranges for males from 16—66 years and 120—190 lbs., the vertical lift made, in meeting test criteria, ranges from 5 to 8 meters per minute. Based on data compiled in this laboratory for metabolic costs of stepping at various heights, the cost of this work would vary from approximately 6 to 9 times the basal metabolic rate. When one considers that the work capacity (expressed as Mets = multiples of basal metabolic rate) may vary from 2 Mets for "sub-normal" individuals to 18 Mets for trained athletes, the 6 to 9 Mets range of Master's Test is hardly adequate. While the test grossly discriminates between "normals" and "sub-normals" it does not accurately gauge the physical capability of individuals; 2) there may be considerable variation in response to the exercise stress within one age-weight group due to physical conditioning differences. Since the minimum metabolic demand is 6 Mets the possibility of overloading certain individuals is present; 3) the range of movement of a subject in performing the Master's Test make the monitoring of physiological parameters very difficult during the work.

Experimentation with a 4-box stepping device showed that the instrument was not ideally suited to the intended purpose. In many cases work at the third step was accompanied by sub-maximal responses but moving to the fourth step induced considerable anaerobic work. The application of a pulse extrapolation technique, however, (Figure 2) showed the test could be quite useful in predicting maximal treadmill performance from sub-maximal responses to work. While the use of extrapolation may limit accuracy this is more than offset by the usefulness of the test in evaluating large groups of individuals where time is an important consideration.

Of the methods investigated with the Gradational Stepper, Procedure III appeared most suitable for "normal" population use as the high correlation ($r = .95$) between treadmill and Procedure III performances would indicate. The physiological responses to stepping in Procedure III approximated most closely those observed in treadmill walking (Table 9). It was repeatedly observed during the different types of work requiring identical values of oxygen intake that pulse rates were higher in stepping than in treadmill walking (Tables 7, 9). One can only speculate on the cause. Asmussen, Christensen and Nielsen[13] have reported discrepancies of this nature when comparable work was performed in different positions. They reasoned that the blood shift to the lower extremities in standing caused a diminished blood pressure in the central veins, leading to a pulse acceleration. On the other hand, an increase of the blood pressure in the central veins in a horizontal or head-down position was followed by a slowing of the heart rate. It appears possible, now, that the more violent vertical jerks in stepping affect the venous blood return hydrostatically in such a way that a lower central venous blood pressure results than in walking. The auxiliary blood pump of respiratory movements may become ineffective because inspiration, favorable for venous return, usually coincides with the upward movements in stepping which tends to decrease the central venous pressure. There is another possibility for the heart rate to be higher in stepping up and down than in walking, at otherwise equal energy expenditures. In stepping, more localized muscle groups are doing the bulk of work. Much stronger impulses from the central nervous system to these muscles are required especially at the greater stepping heights and reflectively the heart rate may become affected. This particular problem deserves further investigation.

The Gradational Stepper may also be used by the clinician interested in assessing the work capacity of normal and sub-normal individuals. A method using treadmill work for pathological cases is described in detail by Naughton and Balke[14]. Basic to the method is the use of workloads calling for energy expenditures in multiples of resting metabolic rates. A similar technique is applicable using the Gradational Stepper. Step test experiments, performed at stepping rates of 24 and 30 per minute, revealed that with both rates the energy expenditure was practically identical for the same unit of vertical lift in a unit of time (see Figure 7). As can be noted, the cost of stepping forward and back on a horizontal level at the rate of "24" amounted to approximately 2 Mets. In all future work with this stepping device for evaluating physical competence a normal or a modified procedure will be followed: for the normal test the first-minute workload will require an energy expenditure of 2.5 Mets, the second minute 3 Mets. From then on the minute-by-minute increments for the "normal" procedure will add one-half of the *b*asal *m*etabolic *r*ate to the previous load, while for the "modified" step test this increase in metabolic rate will only amount

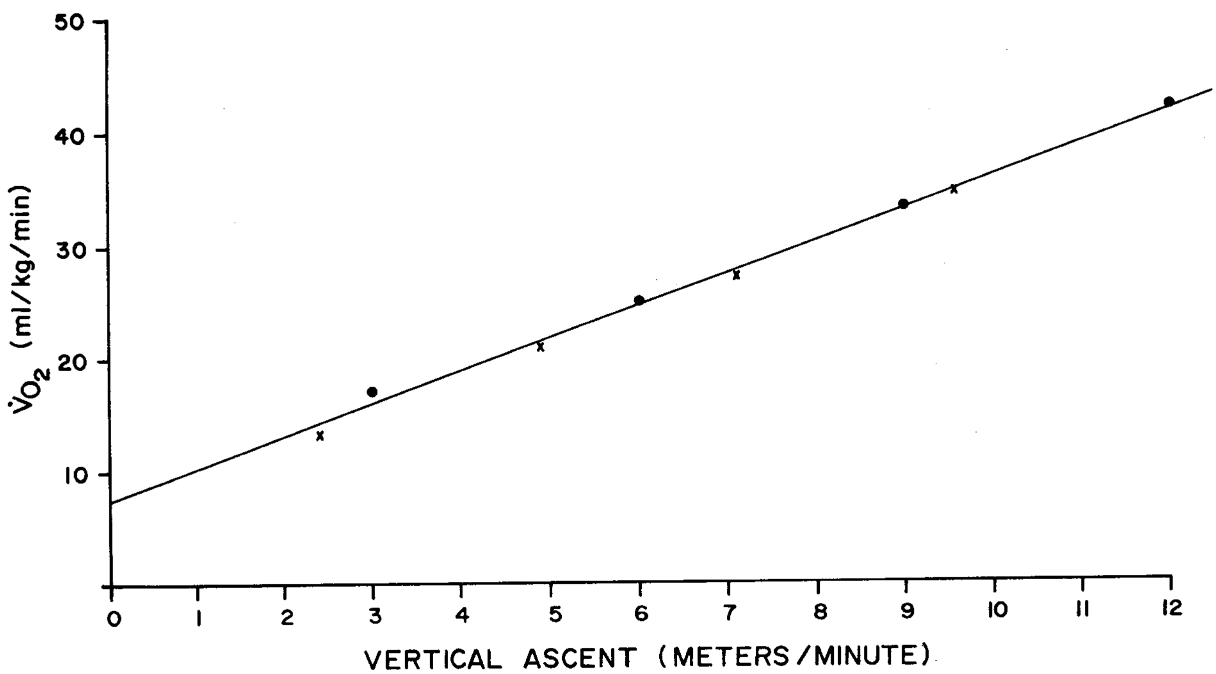

FIGURE 7: The relationship between energy cost and total stepping height at working rates of 30 and 24 steps per minute. Points plotted are mean values for 3 subjects.

to one-third of the BMR. For all practical purposes the BMR amounts to an oxygen consumption of 3.5 ml per kg of body weight. Details of both procedures are given in Table 10. The "modified" test will only be used in cases expected to show abnormally low levels of work capacity.

We are grateful to Don Rowlan, James Turner and Kamal Shanbour for their assistance in this research.

GRADATIONAL STEP TEST

	Normal Procedure Stepping Rate: 30/min			Modified Procedure Stepping Rate: 24/min		
Min.	**Mets**	**Step Height cm**	**Total Vertical Lift m**	**Mets**	**Step Height cm**	**Total Vertical Lift m**
0	1.0	—	—	1	—	—
1	2.5	2	.6	2.5	2.5	.6
2	3.0	4	1.2	3	5.0	1.2
3	3.5	6	1.8	3-1/3	6.7	1.6
4	4.0	8	2.4	3-2/3	8.3	2.0
5	4.5	10	3.0	4	10.0	2.4
6	5.0	12	3.6	4-1/3	11.7	2.8
7	5.5	14	4.2	4-2/3	13.3	3.2
8	6.0	16	4.8	5	15.0	3.6
9	6.5	18	5.4	5-1/3	16.7	4.0
10	7.0	20	6.0	5-2/3	18.3	4.4
11	7.5	22	6.6	6	20.0	4.8
12	8.0	24	7.2	6-1/3	21.7	5.2
13	8.5	26	7.8	6-2/3	23.3	5.6
14	9.0	28	8.4	7	25.0	6.0
15	9.5	30	9.0	7-1/3	26.7	6.4
16	10.0	32	9.6	7-2/3	28.3	6.8
17	10.5	34	10.2	8	30.0	7.2
18	11.0	36	10.8	8-1/3	31.7	7.6
19	11.5	38	11.4	8-2/3	33.3	8.0
20	12.0	40	12.0	9	35.0	8.4

TABLE 10: Relationship between stepping height, vertical lift (in meters per minute) and energy expenditure (expressed as multiples of basal metabolic rate) in the normal and in the modified Gradational Step Test.

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