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A modified Harvard step test for the evaluation of physical fitness.

By

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With 6 graphs in the text.

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Introduction.

As recently shown by ÅSTRAND the determination of the maximal physical working capacity, i. e., the maximal oxygen intake, is time consuming and rather intricate to do. Applied to older individuals it might also be a somewhat dangerous procedure owing to the risk of overstrain. A reliable, submaximal test is therefore desirable.

According to ÅSTRAND's findings young men and women have approximately the same pulse rate — 128 and 138 respectively — when using 50 per cent of their aerobic capacity. It should therefore be possible to estimate the maximal capacity of a similar group by determining the workload on the ergometer bicycle or the oxygen intake at which the heart rate reaches about 130 per min.

For field work a still simpler method would, however, be desirable and a modification of the Harvard step test, which in its original form (see JOHNSON) is a maximal test, ought to be tried out. The reliability of the test should be equal to that of a bicycle test. The aim of the present research was: 1. to design such a submaximal test and to compare its reliability against a work test on a Krogh bicycle ergometer, 2. to evaluate the different factors influencing the heart rate during and after work and 3. to test the applicability of the method for practical use.

Methods.

As subjects students from this college of physical education, 29 males and 31 females between 20 and 30 years (only two male subjects were above 30), were used. For a similar group of students ÅSTRAND determined the maximal physical working capacity. The values obtained here for oxygen intake, lung ventilation, heart rate etc. during cycling with 900 or 600 kgm/min are practically identical with those earlier found (comp. Table 2 and 3); hence the two groups of subjects can be looked upon as equal as far as physical working capacity is concerned.

According to the earlier findings 900 kgm/min for the male students and 600 kgm/min for the females represent close to 50 per cent of their working capacity. These loads were therefore chosen for the bicycle test, and the step test was adapted as to give a corresponding load on the circulation and respiration. The height of the bench was 40 cm for the males and for the females 33 cm (17 per cent lower). Only 22.5 steps per min up and down the bench were done (compared with 30 steps/min in the original Harvard step test). The bicycle tests were done on a Krogh bicycle ergometer with a pedal frequency of 50 per min. It is advisable to use a test of lower intensity for people of 40—70 years of age as the working capacity is reduced with increasing age (ROBINSON). A step test corresponding to 600 kgm/min on the bicycle ergometer was therefore arbitrarily chosen for the males in this age group. The bench was 27 cm high ($^2/_3 \times 40$ cm.) The fact that 600 kgm/min on the bicycle corresponds to a step test on a bench 27 cm high for the men and 33 cm for the women is explained by the greater body weight of the men.

The tests took place at different times of the day and consequently the conditions were not basal. Every test began with 5—10 min rest in lying position, whereafter the heart rate was counted. The step test was performed for 5 min and the pulse rate (radial artery) during work was determined for 15 seconds every min. After some training the heart rate could be exactly determined in that way. In most cases the pulse rate attained a steady value after the second min. If no steady value was obtained the highest (last) value was used. After work the subject sat down and the pulse rate was counted from 1—1½ min after work.

After 5—10 min rest the step test was followed by 5 min cycling on the ergometer.

All subjects performed each test as least three times. The average values of pulse rate during and after work was calculated for every individual. Very high values were observed sometimes following preceding strong physical activity or during a mild infection. Where such "abnormal" values could be explained they were excluded when calculating the average pulse rate. The oxygen intake was determined both during step test and bicycle test the second and the third time

Table 1. *Pulse rate and oxygen intake from three and two different days respectively for 20 women for step test (33 cm, 22.5 steps/min) and bicycle test (frequency 50/min).*

	First	Second	Third
Pulse rate during step test	144.4 ± 1.7 7.5	144.7 ± 2.4 10.4	142.1 ± 1.9 8.3
Pulse rate 1—1½ min after step test	88.0 ± 2.9 12.9	86.9 ± 3.1 13.8	84.6 ± 1.9 8.1
Pulse rate during cycling 600 kgm/min	139.4 ± 2.9 12.7	140.1 ± 3.1 13.8	140.2 ± 2.8 12.3
Pulse rate 1—1½ min after cycling 600 kgm/min	87.5 ± 3.0 13.2	87.4 ± 3.4 15.1	88.9 ± 3.3 14.5
Oxygen intake for step test l/min		1.58 ± 0.04 0.15	1.56 ± 0.04 0.18
Oxygen intake for cycling 600 kgm/min l/min		1.50 ± 0.01 0.05	1.47 ± 0.03 0.13

the subject was tested. The Douglas bag was placed on a table close to the subject to avoid any increase in lifted weight during the step test. The expired air was collected during the last min of work (4—5 min). The average value of the determinations for each individual was used. The respiratory frequency was determined during the time of air collection.

The average values of the pulse rate for 20 female subjects from their first, second and third tests are given in Table 1. They agree very well with one another. These values were used in calculating the error of the method. In a triple determination it is for step test 4.6 and 7.1 beats/min during and after work respectively. For cycling it is 3.6 and 5.8 beats/min respectively.

The blood lactate concentration was determined for 15 subjects after the step test as well as after the bicycle test. Samples of blood were taken between approximately 1½—2½ min and 3½—4½ min after stopping the work, *i. e.*, approximately 7—9 min after beginning of work. The highest attained value was used in the calculation of the average values ranging from 16.7—19.0 mg per cent. These low values make it probable that the energy is delivered aerobically between the 4th and 5th min of work and consequently the values for oxygen intake and mechanical efficiency are reliable, giving evidence that a "steady state" is obtained.

Results and discussion.

1. Oxygen intake and respiration.

The values for oxygen intake are shown in Table 2. As for the male subjects there is no statistically significant difference between the values for step test and bicycle test (2.11 and 2.15 litres O_2-intake/min); for the females the named difference is almost significant (1.56 and 1.48

Table 2. *Oxygen intake, total and per kg body weight, ventilation, respiratory rate and tidal air during step test (22.5 steps/min) and bicycle test for 29 male and 31 female subjects, and a comparison with* ÅSTRANDS *results on 21 male and 31 female subjects.*

	Sex	O_2-intake l/min	O_2-intake (ÅSTRAND) l/min	O_2-intake per kg body weigt ml/min	Vent. l/min (B.T.P.S.)	Vent. (ÅSTRAND) l/min (B.T.P.S.)	Resp. rate	Tidal air
"Step test 40 cm"	♂	2.11±0.04 ±0.20		30.5±0.3 ±1.7	43.3±0.9 ±4.7		19.9±0.9 ±3.0	2.2±0.1 ±0.2
"Bicycle test 900 kgm/min"	♂	2.15±0.02 ±0.10	2.09±0.02 ±0.09	31.3±0.6 ±2.9	45.5±1.0 ±5.4	41.9±1.0 ±4.7	19.6±1.1 ±3.1	2.5±0.1 ±0.4
"Step test 33 cm"	♀	1.56±0.03 ±0.15		26.1±0.3 ±1.4	35.0±0.9 ±5.0		21.7±0.4 ±2.0	1.6±0.1 ±0.3
"Bicycle test 600 kgm/min"	♀	1.48±0.02 ±0.10	1.48±0.02 ±0.08	25.0±0.6 ±3.0	35.9±0.7 ±3.9	34.7±0.9 ±4.8	22.1±0.7 ±3.2	1.7±0.1 ±0.3

respectively). (The values were T-tested according to FISHER; almost significant $P = 0.05 - 0.01$; significant $P = 0{,}01 - 0.001$; highly significant $P < 0.001$.)

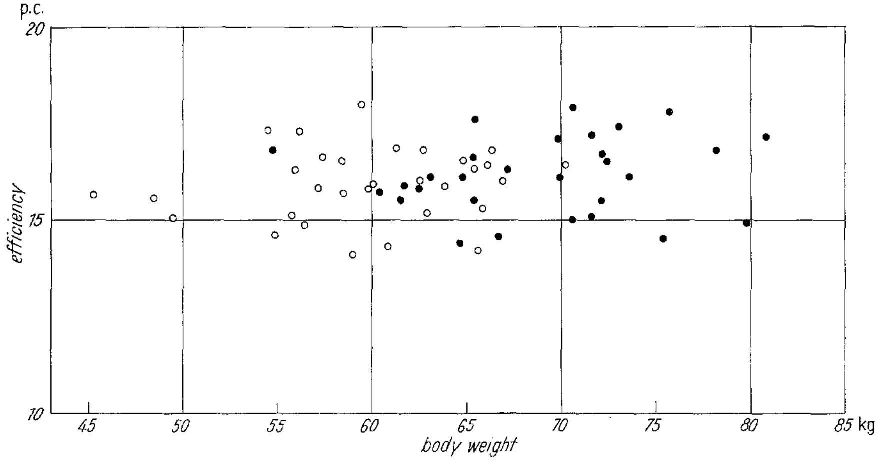

Fig. 1. Step test, mechanical efficiency in relation to body weight. ● = ♂, ○ = ♀.

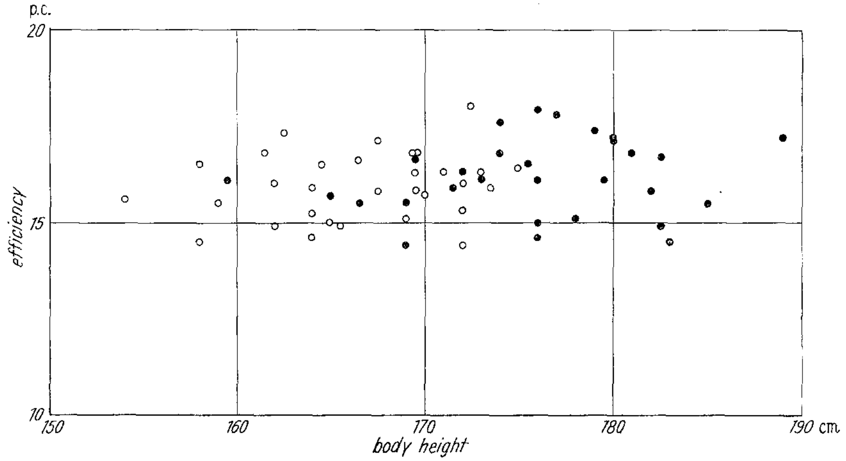

Fig. 2. Step test, mechanical efficiency in relation to body height. ● = ♂, ○ = ♀.

This difference in O_2-intake for the females is not associated with any significant difference in pulse rate during work (see Table 3). Neither for males, nor for females is there any difference in lung ventilation or tidal air when the results of the step test are compared with those of the bicycle test (Table 2).

2. *Mechanical efficiency.*

The mechanical efficiency was determined both for the step test and the bicycle test. As a measure of the total energy delivery the oxygen intake during work is used, and the basal metabolism is calculated

Table 3. *Pulse rate during and after step test (22.5 steps/min) and bicycle test (frequency 50/min) for male and female subjects, and a comparison with* Åstrands *results on 21 male and 31 female subjects.*

	Sex	Number of subjects	Pulse rate during work	Pulse rate 1—1 ½ min after work
"Step test 40 cm"	♂	29	130 ± 1.5 8.1	77 ± 1.7 8.8
"Bicycle test 900 kgm/min"	♂	29	132 ± 1.9 10.1	79 ± 1.9 10.0
"Bicycle test 900 kgm/min" Åstrand	♂	21	128 ± 2.5 11.3	
"Step test 33 cm"	♀	31	140 ± 1.6 9.0	83 ± 2.0 11.1
"Bicycle test 600 kgm/min"	♀	31	138 ± 2.2 12.0	86 ± 2.3 12.7
"Bicycle test 600 kgm/min" Åstrand	♀	31	138 ± 2.1 11.2	

according to the Mayo Foundation Standard. The caloric coefficient of oxygen is sat at 4.90 Calories per litre. The physical work load of the step test was calculated from the bench height, number of steps per min and the subject's body weight. The mechanical efficiency for the step test is for male subjects 16.2 and for female 15.9 per cent. The corresponding values for the bicycle test are 22.8 and 22.7 per cent and the differences in efficiency between the two sexes are not statistically significant. The efficiency is independent of the body weight, (c. f. fig. 1) and of the height (c. f. fig. 2). Range of body weight was 45.4—81.0 kg, and of body height was 154—189 cm.

Table 4. *Oxygen intake and pulse rate during and after step test (22.5 steps/min) and bicycle test (frequency 50/min) for 7 male subjects in two different experimental series.*

	Experimental series	O_2-intake l/min	Pulse rate during work	Pulse rate 1—1 ½ min after work
"Step test 40 cm"	Sept. —52	2.06	124	72
"Bicycle test 900 kgm/min"	,,	2.13	130	75
"Step test 27 cm"	,,	1.46	106	69
"Bicycle test 600 kgm/min"	,,	1.49	109	70
"Step test 40 cm"	May —52	2.13	127	79
"Bicycle test 900 kgm/min"	,,	2.10	128	80

Table 5. *Pulse rate during and after step test (22,5 steps/min) and bicycle test (frequency 50/min) for 24 athletes, 17—25 years old.*

	Pulse rate during work	Pulse rate 1—1 ½ min after work	Number of experiments
"Step test 27 cm"	107.4 ± 1.4 11.3	65.4 ± 1.4 11.3	72
"Bicycle test 600 kgm/min"	110.1 ± 1.5 12.8	69.7 ± 1.6 13.5	70
"Step test 40 cm"	126.6 ± 1.5 12.4	73.6 ± 1.7 14.1	72
"Bicycle test 900 kgm/min"	128.4 ± 1.7 14.2	77.5 ± 1.9 15.5	71

3. *Pulse rate during and after work.*

The average value of pulse rate during the "step test 40 cm" for the male subjects is 130 beats/min, and during cycling 900 kgm/min is 132 (Table 3). The average values after work are 77 and 79 respectively. For the female subjects the average values during work are 140 ("step test 33 cm") and 138 (bicycle test 600 kgm/min) and after work 83 and 86 beats/min respectively. Consequently the two types of work agree well with regard to their load on the circulation. The average pulse rate for the step test is about 10 beats/min higher for the female subjects than for the male. The corresponding difference for cycling is about 6 beats/min (ÅSTRAND 8—10 beats). Both the male and the female students are well-trained and constitute from this point of view a homogeneous group. As the same percentage of the aerobic capacity is likely to have been utilized, this pulse difference must be accepted as a sex difference.

To make sure that the step test with the lower intensity for the males corresponds to 600 kgm/min (22.5 steps/min, 27 cm) 7 male students performed each of the four tests 3 times. The average values of pulse rate for these 7 subjects are approximately the same as those for the

Table 6. *Pulse rate during and after step test (22.5 steps/min) and bicycle test (frequency 50/min) for 25 male subjects at Hagfors steel mill.*

Age	Number of subjects	Pulse rate during "step test 27 cm"	Pulse rate 1—1 ½ min after "step test 27 cm"	Pulse rate during cycling 600 kgm/min	Pulse rate 1—1 ½ min after cycling 600 kgm/min
41—45 years	7	111	75	115	81
46—50 years	7	124	89	123	87
51—55 years	3	122	92	127	94
56—60 years	5	123	94	122	96
61—65 years	3	138	101	143	105

whole group (Table 3 and 4) and therefore the values of the lower intensity will be representative.

Another group of male individuals was tested with the two step tests and the corresponding bicycle tests. This group was constituted by 24 active athletes, 17—25 years old, in a rather different training condition. As there was a period of physical training between the first and the second- third test, the first value of the pulse rate was as a rule somewhat higher than the following. For this reason the average was calculated of all values and not of the individual means. The pulse rates from the two step tests agree well as before with the corresponding bicycle tests (Table 5).

The tests with the lower intensity was applied to 25 males 40—65 years old. They were all workers in the tool department at Hagfors steal mill. The results are too few to allow any definite conclusions but a certain trend towards increasing pulse rate with increasing age seems to exist, indicating a definite decrease in working capacity with age (see Table 6).

As it might be rather difficult for an inexperienced person to count the pulse rate during a step test it would be a great advantage if the work load on the circulation could be estimated from the pulse values after work which is actually done in the original Havard step test. Fig. 3 illustrates the individual correlation between pulse rate after und during

Table 7. *The correlation between pulse rate 1—1½ min after and during work, step test and bicycle test.*

	n	$\bar{X} \pm \varepsilon_{\bar{x}}$	$\bar{y} \pm \varepsilon_{\bar{y}}$	Regr. eq.	Regr. coeff. $b \pm \varepsilon_b$	Regr. coeff. p. c. error	Corr. coeff.	Deviation from regr. line $\delta(y-\bar{y})$	Deviation from regr. line in p. c. of mean ($\bar{y}$)
Pulse rate "after work" in relation to "during work" (subj. R.)	105	158±2.1	106±1.9	$y = -35.3 + 0.89\,x$	0.89±0.03	(2.2)	r = 0.96±0.01	±5.40	(5.1)
Pulse rate "after work" in relation to "during work" (61 individual average values from step test and 66 from bicycle test)	127	136±1.1	83±1.1	$y = -21.4 + 0.77\,x$	0.77±0.06	(7.8)	r = 0.77±0.04	±8.07	(9.7)

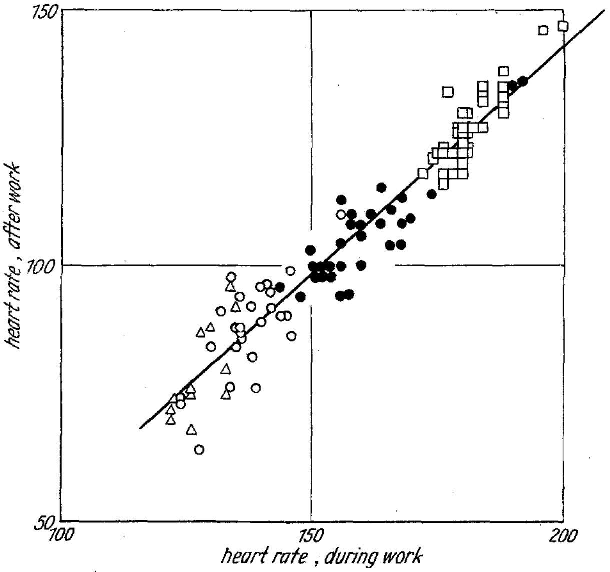

Fig. 3. Pulse rate 1—1 ½ min after work in relation to pulse rate during work for one subject (female). (Statistical data see Table 7). △ = step test, ○ = 600 kgm/min, ● = 900 kgm/min, □ = 1200 kgm/min.

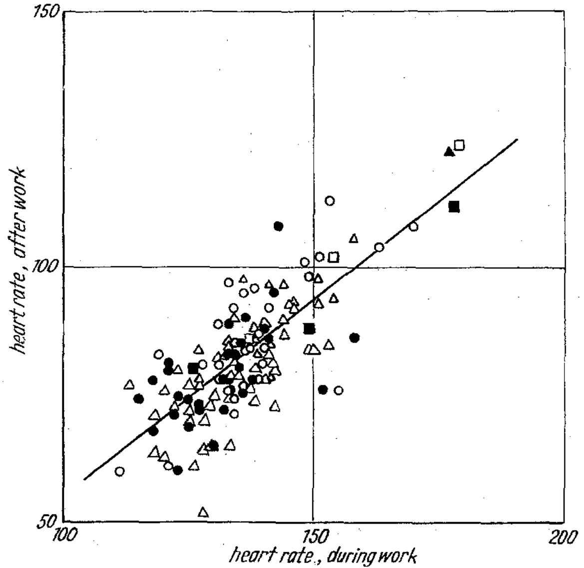

Fig. 4. Pulse rate 1—1 ½ min after work in relation to pulse rate during work. (61 individual average values from step test and 66 from bicycle test.) The figure △ symbolize step test, ●, 900 kgm/min and ○, 600 kgm/min. The figures ■ and □ symbolize the average values of 15 different tests with the intensities of 600, 900 and 1200 kgm/min for two female subjects. The symbol ▲ shows the average from 6 step tests done by a male subject with 30 steps per min on a bench 40 cm high. (Statistical data see Table 7.)

work. The values are derived from 12 step tests and 9 bicycle tests (600 kgm/min) done in March - April - 52, and from 84 bicycle tests (600, 900 and 1200 kgm/min) which are spread over a period from Aug. - 48 to April - 50, representing very different training condition of the subject (R. ♀). The correlation coefficient is r = 0.96 ± 0.01; regression line

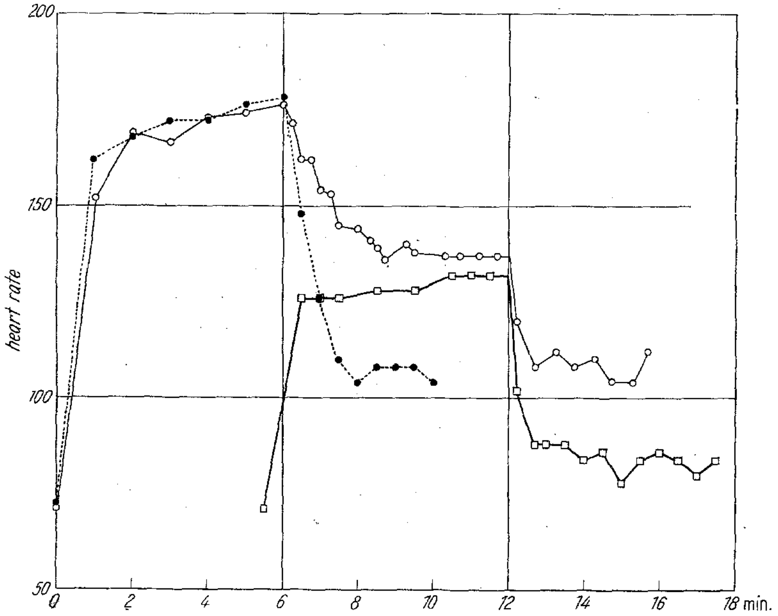

Fig. 5. The effect of a preliminary heavy work on a successive light one. ● = pulse rate 1200 kgm/min, ○ = pulse rate 1200 kgm/min followed by 600 kgm/min, □ = pulse rate 600 kgm/min.

y = — 35.3 + 0.89 x; regression coefficient b = 0.89 ± 0.02 (see Table 7). This good correlation indicates that the pulse rate determined in one and the same subject 1—1 ½ min after work might replace the counting during work.

The correlation between the pulse rate after and during work in the step test and the bicycle test for both male and female subjects is illustrated in fig. 4. The analysis includes 61 individual average values from step test and 66 from bicycle test. A statistical analysis of the correlation between heart rate after and during work gives the correlation coefficient r = 0.77±0.04; regression line y = — 21.4+0.77 x; regression coefficient b = 0.77±0.06. (See further Table 7.) From this data it is evident that the pulse rate 1—1 ½ min after work only gives a rough idea of the pulse rate during work if the results are compiled from different subjects.

Table. 8. *Pulse rate during continuous and interrupted cycling tests for two female subjects, A. (65.5 kg, 170 cm) and R. (58.5 kg, 165.5 cm)*

Subj.	Numb. of exp.	Pulse rate during continuous cycling test			Numb. of exp.	Pulse rate during interrupted cycling test			Pulse rate after 1200 kgm/min	
		600 kgm/min	900 kgm/min	1200 kgm/min		600 kgm/min	900 kgm/min	1200 kgm/min	Continuous cycling	Interrupted cycling
A.	14	121 ± 1.4 5.0	152 ± 1.6 6.0	183 ± 2.2 8.0	14	127 ± 1.9 7.1	150 ± 1.5 5.5	187 ± 3.6 13.5	112 ± 1.7 6.3	113 ± 2.2 8.3
R.	17	132 ± 1.7 7.3	161 ± 1.7 7.5	183 ± 1.2 5.3	18	137 ± 2.0 8.2	155 ± 1.5 6.2	181 ± 1.6 6.3	128 ± 1.7 7.1	126 ± 2.0 8.0

If the work is relatively light, the pulse rate after work will return to the normal resting value so quickly that the 1—1½ min pulse rate cannot be used for any estimation of the pulse rate during work.

4. *The influence of preliminary work.*

The effect of a preliminary bout of heavy work on the pulse rate achieved during a subsequent period of lighter work is illustrated in fig. 5. The female subject was cycling with 1200 kgm/min for 6 min whereafter the intensity was changed to 600 kgm/min. The pulse rate reached a constant level with 600 kgm/min after 2—3 min. Furthermore, separate tests with 600 and 1200 kgm/min were done. When 600 kgm/min was preceded by 1200 kgm/min the pulse rate was slightly higher than if the 600 kgm/min work-period was preceded by a period of rest, which is probably related to the oxygen debt that has to be paid of after the 1200 kgm work. It is notable that the pulse rate during recovery, for several min remained on a level usually seen after 1200 kgm/min.

When the above mentioned bicycle tests with the intensities of 600, 900 and 1200 kgm/min were done the 900 test was first performed. Thereafter 600 and 1200 kgm/min were done. Before each intensity the pulse rate was down to the same level as before the test. As a comparison the tests were performed continuously. The subject began with 600 and changed after 6 min to 900 and after 6 min more to 1200 kgm/min (Method compare SJÖSTRAND). Those tests were done by 2 subjects and the results are given in Table 8. The difference between the pulse rate of the interrupted and the continuous tests is not statistically significant; the same holds true for the pulse rate after 1200 kgm/min. The preliminary work must obviously be fairly high (in this case higher than 900 kgm/min) or the work time longer than that here used if a higher pulse rate during and after work shall be reached as compared with "normal" values. Such tests were done in the morning and also in the afternoon. No difference was found between the a.m. and p.m. values.

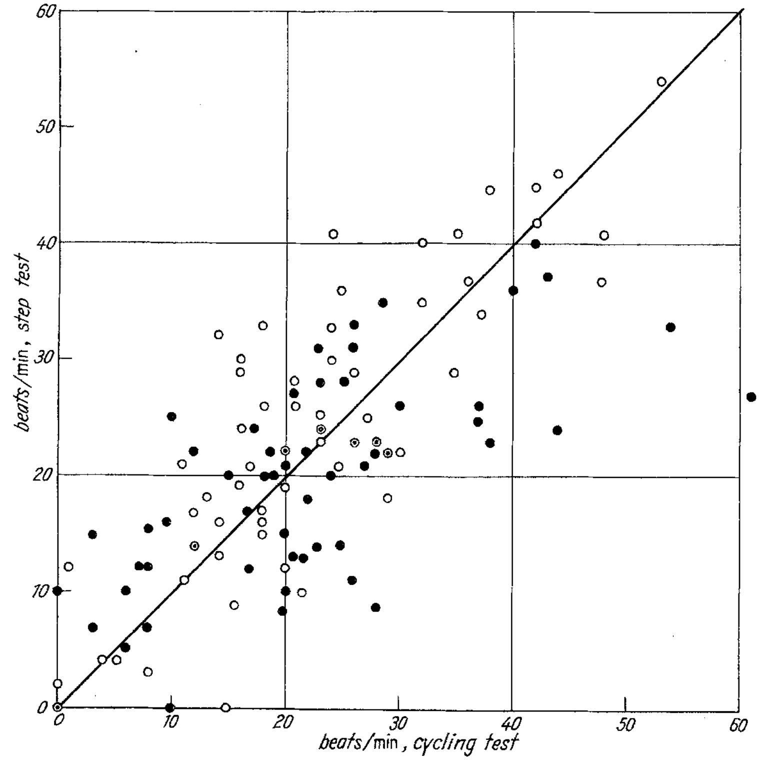

Fig. 6. Evaluation of physical fitness based on the pulse rate during and after step test and bicycle test. ● = pulse rate during work, ○ = pulse rate after work.

5. Evaluation of physical fitness based on the pulse rate during and after work.

Using the average values of the pulse rate from step test and from bicycle test the subjects can be classified with regard to physical fitness. Thus the subject who attained the lowest heart rate during and after work respectively were considered to possess the highest working capacity. The subject who worked with the lowest pulse rate is represented in origo (see fig. 6) and each of the others is marked corresponding to the number of pulse beats that his or her frequency differs from the lowest one. Any difference between male and female subjects does not exist in this connection and therefore all values are included in the fig.

Table 9. *Oxygen intake and pulse rate during and after step test (40 cm) and bicycle test (900 kgm/min) for 7 male subjects 54.9—65.0 kg and 5 male subjects 75.0—81.0 kg body weight.*

	Step test, 22.5 steps/min				Bicycle test, frequency 50/min			
	O_2-intake l/min	O_2-intake per kg body weight ml/min	Pulse rate during work	Pulse rate 1—1½ min after work	O_2-intake l/min	O_2-intake per kg body weight ml/min	Pulse rate during work	Pulse rate 1—1½ min after work
54.9—65.0 kg	1.93±0.06 0.16	31.5±0.5 1.2	131.1±2.3 6.1	81.4±4.5 11.9	2.13±0.04 0.10	34.8±0.7 1.8	140.3±2.4 6.3	86.4±4.5 11.8
75.0—81.0 kg	2.36±0.09 0.19	30.2±1.1 2.5	134.6±2.7 5.9	80.2±4.5 9.9	2.16±0.04 0.07	27.5±0.3 0.7	130.6±3.9 8.6	79.8±4.0 9.0

For some subjects the step test gave a lower number than the bicycle test, for others the reverse holds true. This must be seen against the background that the energy output in cycling is relatively independent of the body weight. Any difference in the result when using the pulse rate during or after work as a basis for the evaluation can not be observed.

General discussion.

In a step test but not in a bicycle test the work load increases with the body weight. The results of Table 9 illustrate this. In this table the average values of oxygen intake and pulse rate are given for the five male subjects with the highest range of body weight (between 75.0—81.0 kg) and for the seven with the lowest range (between 54.9—65.0 kg). The difference in the total oxygen intake for the two groups in step test is statistically significant ($P = 0.01$—0.001) but this is not the case for the oxygen intake per kg body weight or for the pulse rate. The corresponding values for the total oxygen intake in bicycle test show no difference but the difference in the oxygen intake per kg body weight is highly significant ($P < 0.001$) and the difference in pulse rate during work is on the limit of being almost significant ($P = 0.05$). The scattering of oxygen intake l/min and ml/kg body weight and of pulse rate for all subjects suggest the same relationship (see Table 2 and 3). If the same relative stress is desired in a bicycle test for individuals of different body weight, the load should be varied with the weight of the subject.

The step test in this form is feasible when testing physical fitness of healthy persons in a good physical condition.

For older individuals or for the less fit, the intensity must be lower. By testing persons in industrial work an intensity corresponding to 600 kgm/min for men and 400 kgm/min for women is suggested; the bench heights would be 27 and 22 cm respectively.

During work the relationship between pulse rate and the ratio attained $\frac{O_2\text{-intake}}{\text{maximal } O_2\text{-intake}}$ shows fairly small individual variations (the standard deviation in pulse rate was 7.8—9.4 at the ratio 0.50 and 0.70 (ÅSTRAND). Consequently one should be able to calculate the aerobic capacity of a given individual if the oxygen intake and the pulse rate in a certain step test is known.

Based on the assumption that the mechanical efficiency in a step test with a bench height of 27, 22, 40 or 33 cm is 16 per cent (see p. 239) the calculated O_2-intake for individuals of different body weight and the corresponding load on the bicycle ergometer (mechanical efficiency 23 per cent, (see p. 239), are given in Table 10, 11, 12 and 13. From the pulse rates of 95, 110, 125, 140 and 155 per min for males provided to correspond to 26, 37, 48, 59 and 70 per cent of the aerobic capacity the different maximal aerobic capacities were calculated. The pulse rates of 110, 120, 130, 140 and 150 per min corresponding to 32, 39, 46, 53 and 60 per cent of the aerobic capacity were chosen for the females. (The basal O_2-intake was assumed to be in accordance with the Mayo Foundation Standard. The average height of men was set at 175 cm and of women at 165 cm and average age at 25 years. One litre of oxygen was calculated to give 4.90 Cal.)

Table 10. *Estimated oxygen intake for "step test 27 cm" and the corresponding load on the bicycle ergometer for male subjects with different body weight and their aerobic capacity calculated from the pulse rate (p.r.) during the test. In parenthesis is denoted the percentage of the maximal aerobic capacity that is utilized at the given pulse rate.*

			Maximal aerobic capacity, O_2-intake l/min				
Body weight kg	O_2-intake "step test 27 cm" l/min	Load for the bicycle test kgm/min	p.r. = 95 (26 %)	p.r. = 110 (37 %)	p.r. = 125 (48 %)	p.r. = 140 (59 %)	p.r. = 155 (70 %)
51—55	1.2	470	4.6	3.2	2.5	2.0	1.7
56—60	1.3	510	5.0	3.5	2.7	2.2	1.9
61—65	1.4	560	5.4	3.8	2.9	2.4	2.0
66—70	1.5	600	—	4.1	3.1	2.5	2.1
71—75	1.6	640	—	4.3	3.3	2.7	2.3
76—80	1.7	690	—	4.6	3.5	2.9	2.4
81—85	1.8	730	—	4.9	3.8	3.1	2.6
86—90	1.9	780	—	5.1	4.0	3.2	2.7
91—95	2.0	820	—	5.4	4.2	3.4	2.9
96—100	2.1	870	—	—	4.4	3.6	3.0

Table 11. *"Step test 22 cm", female subjects. Further see Table 10.*

			Maximal aerobic capacity, O_2-intake l/min				
Body weight kg	O_2-intake "step test 22 cm" l/min	Load for the bicycle test kgm/min	p.r. = 110 (32 %)	p.r. = 120 (39 %)	p.r. = 130 (46 %)	p.r. = 140 (53 %)	p.r. = 150 (60 %)
46—50	0.9	340	2.8	2.3	2.0	1.7	1.5
51—55	1.0	390	3.2	2.6	2.2	1.9	1.7
56—60	1.1	430	3.4	2.8	2.4	2.1	1.8
61—65	1.1	450	3.6	2.9	2.5	2.2	1.9
66—70	1.2	470	3.8	3.1	2.6	2.3	2.0
71—75	1.3	520	4.1	3.3	2.8	2.5	2.2
76—80	1.4	560	—	3.6	3.0	2.6	2.3
81—85	1.5	610	—	—	3.3	2.8	2.5
86—90	1.6	650	—	—	3.5	3.0	2.7

Table 12. *"Step test 40 cm", male subjects. Further see Table 10.*

			Maximal aerobic capacity, O_2-intake l/min				
Body weight kg	O_2-intake "step test 40 cm" l/min	Load for the bicycle test kgm/min	p.r. = 95 (26 %)	p.r. = 110 (37 %)	p.r. = 125 (48 %)	p.r. = 140 (59 %)	p.r. = 155 (70 %)
51— 55	1.6	680	(6.2)	4.3	3.3	2.7	2.3
56— 60	1.8	740	—	4.9	3.8	3.1	2.6
61— 65	1.9	810	—	5.1	4.0	3.2	2.7
66— 70	2.1	870	—	—	4.4	3.6	3.0
71— 75	2.2	940	—	—	4.6	3.7	3.1
76— 80	2.4	1000	—	—	5.0	4.1	3.4
81— 85	2.5	1070	—	—	5.2	4.2	3.6
86— 90	2.6	1130	—	—	—	4.4	3.7
91— 95	2.8	1200	—	—	—	4.7	4.0
96—100	2.9	1260	—	—	—	4.9	4.1

Table 13. *"Step test 33 cm", female subjects. Further see Table 10.*

			Maximal aerobic capacity, O_2-intake l/min				
Body weight kg	O_2-intake "step test 33 cm" l/min	Load for the bicycle test kgm/min	p.r. = 110 (32 %)	p.r. = 120 (39 %)	p.r. = 130 (46 %)	p.r. = 140 (53 %)	p.r. = 150 (60 %)
46—50	1.2	510	3.8	3.1	2.6	2.3	2.0
51—55	1.4	560	4.4	3.6	3.0	2.6	2.3
56—60	1.5	610	—	3.8	3.3	2.8	2.5
61—65	1.6	670	—	4.1	3.5	3.0	2.7
66—70	1.7	720	—	—	3.7	3.2	2.8
71—75	1.8	770	—	—	3.9	3.4	3.0
76—80	1.9	830	—	—	4.1	3.6	3.2
81—85	2.1	880	—	—	—	4.0	3.5
86—90	2.2	930	—	—	—	4.2	3.7

The use of the tables can be illustrated by the following example (Table 10). If a male subject with a body weight of 64 kg and with an O_2-intake of 1.4 litres per min has a pulse rate of 110 then 37 per cent of his aerobic capacity is engaged; his maximal aerobic capacity will therefore correspond to about 3.8 litres of O_2 per min. If, however, his pulse rate had been 125 then 48 per cent of his aerobic capacity would be engaged, and he should only be able to consume 2.9 litres of O_2 per min.

Assuming that 50 per cent of the aerobic capacity is close to the upper limit of what one should allow to be used during manual labour, a man below 55 kg body weight should not be placed on a job that asks for more than 1.25 litres of oxygen per min. On the other hand a man of 80 kg should be able to handle a job temporarily with an oxygen intake of 1.8 litres per min. Both should have a pulse rate of 125 during a step test with a bench height of 27 cm and 22.5 steps/min.

Recently (1950) MÜLLER introduced a test procedure to estimate the physical working capacity. The Leistungspulsindex „gibt an, wieviel die korrigierte Pulsfrequenz je mkg/sec oder je 10 W Leistungszunahme ansteigt“ and is based on the well known fact that the increase in heart rate for a given increase in work load is less for the trained and fit than for the unfit. It does not, however, consider the actual level of the heart rate above the normal resting level or below the maximal value.

Undoubtedly the Leistungspulsindex can give valuable information as to the working capacity. In its present form the method uses a special bicycle ergometer and an electrical pulse counter which might restrict its practical use for field work.

A step test of the here mentioned type could be a useful tool on placing the right man on the right job. It would help to reveal physical insufficiency due to illness at an early state and thereby help to avoid overstrain of the workmen engaged in heavy manual labour.

Summary.

A submaximal test for estimating the physical working capacity has been worked out and compared with a more complicated bicycle test. The testing procedure is a modification of the Harvard step test (JOHNSON) which in its original form is a maximal test. The pulse rate was counted during work.

The bench height was 40 cm for young males and 27 for the older ones and for the females 33 cm; 22.5 steps per min.

The average values for "step test 40 cm" and "bicycle test 900 kgm/min" for male subjects were: oxygen intake 2.11 ± 0.04 and 2.15 ± 0.02 l/min; pulse rate during work 130 ± 1.5 and 132 ± 1.9 beats/min respectively. The average values for "step test 33 cm" and "bicycle test 600 kgm/min" for female subjects were: oxygen intake

1.56 ± 0.03 and 1.48 ± 0.02 l/min; pulse rate during work 140 ± 1.6 and 138 ± 2.2 beats/min respectively. The mechanical efficiency did not vary with the body height or weight.

As the aerobic capacity for trained individuals without excessive fat is closely correlated to the body weight (Åstrand) the light ones will be tested at a relatively higher intensity than the heavy ones using the bicycle test with a fixed load. In the step test the load varies with the body weight and all subjects will have to engage the same percentage of their aerobic capacity. To obtain the same result with the bicycle test, the load must be individually adapted.

Values are given whereby the aerobic capacity can be roughly estimated from the pulse rate during step test and bicycle test.

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