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Standardization of Submaximal Exercise Tests*

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It is often impossible to measure the reference standard of cardiorespiratory fitness (the maximum oxygen intake) directly, and there is thus a need for subsidiary standard procedures based on body responses to submaximal exercise. In order to reach agreement on such procedures, a recent international working party has compared a variety of possible tests involving step, bicycle, and treadmill exercise; criteria of comparison included the extent of habituation and learning with each procedure, the physiological responses, and practical considerations. There was little to commend submaximal exercise on the treadmill. Anxiety and learning were least on the bicycle ergometer, but significant anaerobic metabolism developed at loads of more than 55 % of aerobic power ; the main role of the bicycle was thus in laboratory tests requiring arm immobilization. The step test was cheap and portable, subjects showed relatively little anxiety or learning, and good-quality electrocardiograms were obtained : it thus seemed the procedure of choice for field tests. The results of all forms of submaximal test should be extrapolated to maximum oxygen intake in order to overcome difficulties arising from differences in the age and fitness of subjects. Four common extrapolation procedures, based respectively on one to four measurements of oxygen consumption and pulse rate, yielded similar predictions of maximum oxygen intake. A single progressive test, in which the exercise load was increased at the end of every third minute, gave an identical prediction of maximum oxygen intake to that obtained from a series of 4 discontinuous tests. The progressive test was thus the preferred procedure ; however, in subjects with some circulatory delay, it might be necessary to replace the four 3-min loads by three 4-min loads.

The directly measured maximum oxygen intake is now widely accepted as one unequivocal reference standard of cardiorespiratory fitness. Various possible methods for the measurement of this parameter have been compared (Shephard et al., 1968), and procedures agreed for laboratory and field studies. Unfortunately, maximum oxygen intake cannot be measured directly on all segments of the population, and there is thus a need for secondary standards, forms of submaximal exercise that can be applied to athletic, sedentary, and diseased subjects under a wide range of environmental conditions. Standardization of submaximal exercise tests is currently sought by both the World Health Organization (WHO Meeting on Exercise Tests in Relation to Cardiovascular Function, 1968) and the International Biological Programme. The latter has as one of its objectives a comparison of the working capacity of small and widely scattered populations, and it is planned that the necessary data will be collected by a substantial number of co-operating laboratories, using mutually agreed procedures.

At present, 3 modes of submaximal exercise (step, bicycle, and treadmill) all have their strong advocates. However, we lack objective data on their relative merits. There are at present no comparisons of the levels of anxiety and of individual variations in mechanical efficiency for the 3 forms of exercise. There is also disagreement on the optimum pattern of exercise; some investigators favour a series of tests at graded work-loads, while others prefer a continuous test. Finally, there are differences in the method of reporting findings; some authors quote the results directly (for example, the pulse rate at

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a fixed level of oxygen consumption) while others extrapolate to estimate the maximum oxygen intake.

One of the objectives of an international working party which met in Toronto in the summer of 1967 under the auspices of the International Biological Programme was to resolve some of these problems. A panel of 24 subjects each attended the laboratory on 15 occasions to perform a variety of submaximal step, bicycle, and treadmill tests according to a Latin-square design. The findings from these experiments are the subject of the present paper.

MATERIAL AND METHODS

Subjects and experimental plan

The subjects were the 24 young Canadian men (age range 20–40 years, mean 26.4 years) who also participated in measurements of maximum oxygen intake (Shephard et al., 1968). They attended the laboratory at the same hour on each of 10 successive working days, performing submaximal exercise on the step, treadmill, or bicycle ergometer according to the experimental design of Table 1. During the following 2 weeks, they performed 10 maximum oxygen intake tests, becoming thoroughly habituated to all 3 forms of exercise. There was then a final week of submaximal exercise on step, bicycle, or treadmill. All measurements were made with the subjects resting, but not basal. No observations were obtained earlier than 1 hour after a meal, but in view of the repeated nature of the testing, further restriction of the subjects was not practicable.

TABLE 1

EXPERIMENTAL DESIGN FOR 6 GROUPS OF SUBJECTS PERFORMING SUBMAXIMAL STEP (ST), BICYCLE ERGOMETER (BI) AND TREADMILL (TM) EXERCISE

	Group					
	1	2	3	4	5	6
Days 1-3, discontinuous	ST	ST	BI	BI	TM	TM
Day 4, continuous	ST	ST	BI	BI	TM	TM
Day 5, discontinuous	ST	ST	BI	BI	TM	TM
Days 6-8, discontinuous	BI	TM	ST	TM	ST	BI
Day 9, continuous	BI	TM	ST	TM	ST	BI
Day 10, discontinuous	BI	TM	ST	TM	ST	BI
Days 11-20	All subjects performed 10 measurements of maximal oxygen intake, the last four being with the mode of exercise to be followed in the final week of testing					
Days 21-23, discontinuous	TM	BI	TM	ST	BI	ST
Day 24, continuous [a]	TM	BI	TM	ST	BI	ST
Day 25, discontinuous	TM	BI	TM	ST	BI	ST

[a] Subjects also performed a continuous maximum test on this day.

Modes of exercise

The double 9-in (23-cm) (Masters) type of step (Shephard, 1967) was chosen because the height was familiar to the subjects and a comfortable cadence of stepping was obtained during submaximal exercise. The 2 stairs were climbed with 3 paces, giving a rhythm of 60–150 steps/min, depending on the exercise load. Subjects were paced by a metronome, and care was taken to ensure that they stood erect at each ascent, and placed both heels upon the ground with each descent.

The bicycle ergometer was a mechanically braked Fleisch Ergostat (Jacquet Ltd, Basle, Switzerland). This had several advantages over other mechanical and electrical ergometers, particularly damping of the brake belt, automatic correction of changes in friction caused by heating of the belt, the direct use of calibrated weights, and visual indication of the pedal speed. The saddle height was adjusted to allow full extension of the legs during cycling. Subjects were permitted to place either their toes or their insteps on the pedals, as seemed comfortable to them, but they were then required to maintain a constant technique throughout the tests. A constant pedal speed of 60 rev/min was adopted.

The treadmill exercise was uphill running, or in a few of the less fit individuals uphill walking. Combinations of treadmill speed and slope suited to the required oxygen consumption were estimated from a recent modification (Shephard, 1968) of the nomogram of Margaria et al. (1963).

Patterns of exercise loading

Irrespective of the type of test to be performed, subjects were allowed an initial rest period of 15 min. In the discontinuous tests, individual bouts of exercise were of 5 min duration, gas samples being collected and pulse rates recorded during the fifth minute at each load. Work-loads were adjusted to give 4 pulse rates, spaced as evenly as possible, in the range 100–170/min. Intervening rest periods were graded with the intensity of exercise (7 min, 8 min, and 10 min respectively). In the continuous tests, the duration of exercise was shortened to

3 min at each of 4 intensities. Pulse rates were recorded and gas samples collected during the third minute at each level of exercise.

RESULTS

Anxiety and habituation

Many procedures for the interpretation of submaximal tests of cardiorespiratory function are based on the assumption that the pulse rate is constant at a given fraction of an individual's maximum aerobic power. The accuracy of such procedures is thus limited by non-metabolic increases of pulse rate induced by anxiety and adverse environmental conditions. The level of anxiety induced by a given mode of exercise depends upon the apparent difficulty of the test and any problems that may arise during its performance; it is also influenced by the personality of the subject and the general atmosphere in the laboratory, and tends to diminish with repetition of the test (the process sometimes described as habituation; Glaser, 1966; Shephard, 1966a).

The phenomenon has been evaluated by fitting a linear regression of pulse rate on oxygen consumption to the data from each individual on each day of testing, and interpolating or extrapolating to a common oxygen consumption of 1.5 litres/min, converted to standard temperature and pressure, dry (STPD). Irrespective of the mode of exercise, there was some decrease in the average pulse rate from Day 1 to Day 5 (Table 2), this difference being statistically significant for the treadmill and the step test ($P < 0.001$) but not for the bicycle ergometer. During the second week, the decreases in pulse rate were smaller and less consistent, and during the fifth week (after 2 weeks of maximal exercise) no change occurred.

Pooling values for the 3 modes of exercise, the pulse rate at an oxygen consumption of 1.5 litres/min decreased from 123.3/min on Day 1 to 117.0/min on Day 5; this is equivalent to an increase of about 0.5 litre/min in the predicted maximum oxygen intake. Since 2 weeks of maximum effort tests improved the directly measured oxygen uptake by an average of only 0.18 litre/min (Shephard et al., 1968) the major part of the decrease in pulse rate must thus represent habituation or a lessening of anxiety rather than training. The high pulse rates during the treadmill test on Week 2, Day 5 are thought to

TABLE 2
CHANGES IN PULSE RATE AT OXYGEN INTAKE OF 1.5 litres/min WITH REPETITION OF SPECIFIC WORK TESTS

Test	Week	Day 1	Day 2	Day 3	Day 4 (progressive)	Day 5
TM	1	127	122	124	(120)	117
	2	117	108	109	(108)	116
	5	118	116	118	(104)	119
	1, 2 & 5	121	115	117	(111)	117
BI	1	117	118	118	(118)	115
	2	120	119	122	(116)	117
	5	107	111	110	(108)	108
	1, 2 & 5	115	116	117	(114)	113
ST	1	126	121	118	(117)	119
	2	120	116	118	(115)	116
	5	109	108	108	(113)	108
	1, 2 & 5	118	115	115	(115)	114

represent a loss of habituation when the subjects saw a safety mat installed in preparation for the maximum effort tests.

Physiological responses

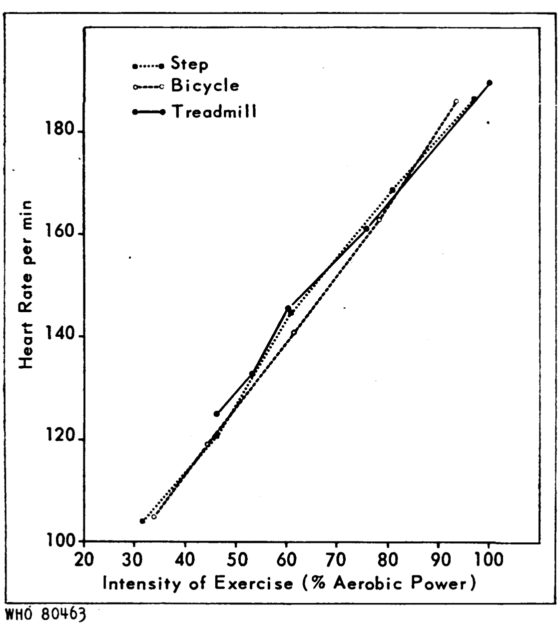
The cardiac and ventilatory responses to the 3 modes of exercise are compared in Fig. 1, 2, and 3.

In agreement with earlier observations by one of us (Shephard, 1966b), when pulse rate was plotted against intensity of effort expressed as a percentage of the individual's maximum aerobic power (Fig. 1) the physiological response was rather similar for stepping, cycling, and uphill treadmill running. At the lowest work-loads, the influence of anxiety was such that the treadmill and step pulse readings were a little higher than those for the bicycle ergometer. At the highest work-loads, the difference was reversed, in keeping with the observed differences of cardiac stroke volume (Shephard et al., 1968).

Detailed data on the cardiovascular responses to bicycle and treadmill exercise are presented in Fig. 2. Unfortunately, the rebreathing technique could not readily be performed during stepping. In 2 of the subjects (1 tested on the treadmill, 1 on the bicycle),

FIG. 1

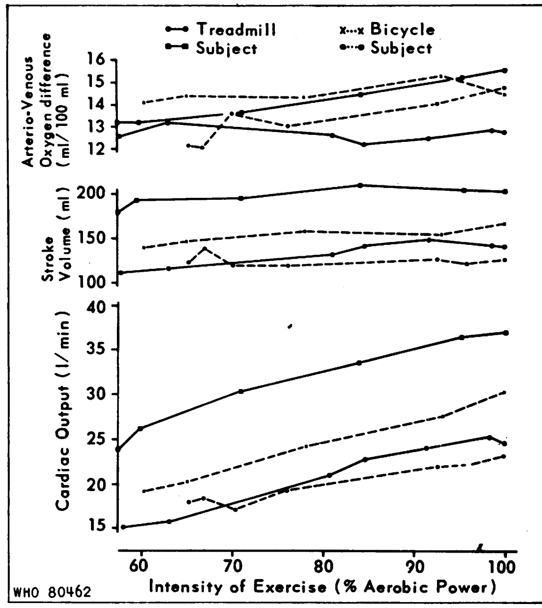
RELATIONSHIP BETWEEN PULSE RATE AND INTENSITY OF EFFORT (% OF AEROBIC POWER) [a]



[a] Mean values for 24 subjects carrying out 3 forms of submaximal exercise for the first time (days 1, 6, and 21).

FIG. 2

RELATIONSHIP BETWEEN INTENSITY OF EFFORT (% OF AEROBIC POWER) AND ARTERIOVENOUS OXYGEN DIFFERENCE, STROKE VOLUME, AND CARDIAC OUTPUT [a]



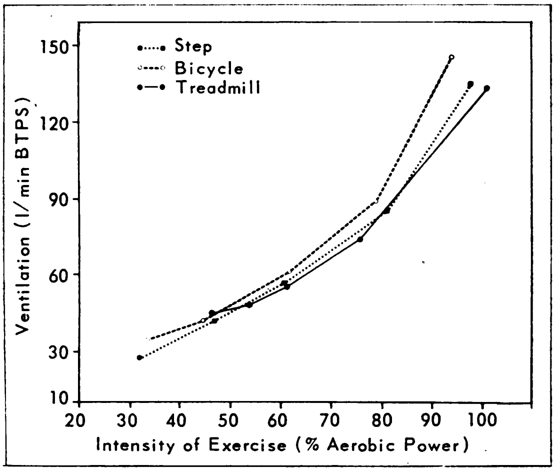
[a] Two subjects exercising on treadmill (solid lines) and 2 subjects exercising on bicycle ergometer.

the arteriovenous (a-v) oxygen difference remained substantially unchanged over the range 50%–100% of aerobic power. In the remaining 2, the a-v oxygen difference continued to increase slowly until the maximum aerobic power was reached; however, in all 4 subjects the main increase of a-v difference was from rest to 50% of aerobic power. In the 2 treadmill runners, the stroke volume apparently reached a plateau of about twice the resting value at ∾80% of aerobic power; in those exercised on the bicycle ergometer, the plateau occurred perhaps rather earlier. In all 4 subjects, cardiac output continued to increase fairly uniformly through to maximum aerobic power.

The respiratory minute-volume (Fig. 3), was a little greater for the bicycle ergometer than for the other 2 forms of exercise; this discrepancy was most marked at high work rates. An explanation of the differences in ventilation is suggested by measurements of blood lactate (Fig. 4). At all intensities of effort, lactate levels were highest on the bicycle ergometer. Significant anaerobic metabolism occurred at approximately 55% of aerobic power when

FIG. 3

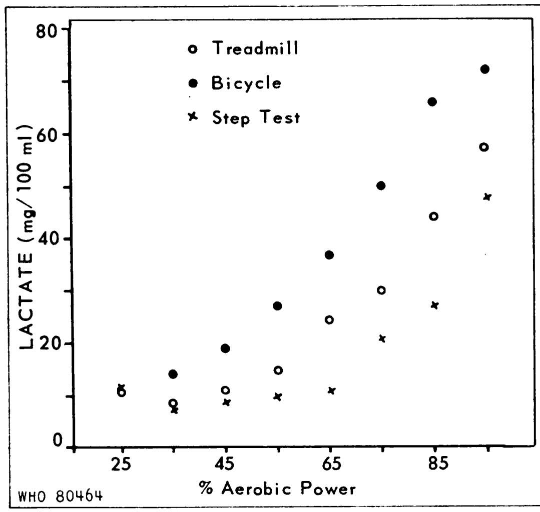
RELATIONSHIP BETWEEN RESPIRATORY MINUTE-VOLUME AND INTENSITY OF EFFORT (% OF AEROBIC POWER) [a]



[a] Mean values for 24 subjects carrying out 3 forms of submaximal exercise for the first time (days 1, 6, and 21).
BTPS = Body temperature, pressure, and saturation.

FIG. 4

RELATIONSHIP BETWEEN LACTATE CONTENT OF ARTERIALIZED CAPILLARY BLOOD 2–4 MINUTES AFTER EXERCISE AND INTENSITY OF EFFORT (% OF AEROBIC POWER) [a]



[a] Averaged results from 360 observations on 24 subjects. Curves have been fitted to the data the for 3 types of exercise, as follows:

Treadmill $y = 31.24 - 1.098x + 0.01487\,x^2$
Step test $y = 23.76 - 1.098x + 0.014871\,x^2$
Bicycle $y = 43.61 - 1.098x + 0.01487\,x^2$

where y is the lactate level (mg/100 ml) and x is the oxygen consumption expressed as a fraction of aerobic power. The difference in level of the 3 curves is highly significant ($P<0.001$).

cycling, 65% of aerobic power when running on the treadmill, and 80% of aerobic power when stepping.

Mechanical efficiency

The mean efficiency of performance for the step test experiments is shown in Table 3. Results were

TABLE 3

RELATIONSHIP BETWEEN WORK-LOAD AND MECHANICAL EFFICIENCY [a] OF EXERCISE ON STEP TEST

Laboratory subjects (n=10)			Test subjects before maximum exercise (n=15)			Test subjects after maximum exercise (n=9)		
Rate of working (kgm min)	Mean efficiency (%)	Coeff. of variation (%)	Rate of working (kgm min)	Mean efficiency (%)	Coeff. of variation (%)	Rate of working (kgm min)	Mean efficiency (%)	Coeff. of variation (%)
320	16.6	7.8	335	16.5	11.9	314	15.5	13.6
480	17.1	5.9	504	17.0	11.2	515	16.3	8.1
640	16.4	6.0	662	15.8	9.0	700	15.6	7.8
800	15.0	9.7	832	14.6	12.3	850	14.7	11.1
All loads	16.3	7.4	All loads	16.0	11.1	All loads	15.5	10.2

[a] Mechanical efficiency calculated from gross oxygen cost during effort, less predicted basal metabolism of 0.67 kcal/m² of body surface, assuming a constant energy equivalent of 5 kcal per litre of oxygen. Data for test subjects averaged over 5 days.

TABLE 4

RELATIONSHIP BETWEEN WORK-LOAD AND MECHANICAL EFFICIENCY [a] OF EXERCISE ON BICYCLE ERGOMETER

Laboratory subjects ($n=10$)			Test subjects before maximum exercise ($n=16$)			Test subjects after maximum exercise ($n=8$)		
Rate of working (kgm/min)	Mean efficiency (%)	Coeff. of variation (%)	Rate of working (kgm/min)	Mean efficiency (%)	Coeff. of variation (%)	Rate of working (kgm/min)	Mean efficiency (%)	Coeff. of variation (%)
384	22.9	11.0	398	21.4	10.0	555	21.6	6.4
576	23.6	6.7	607	22.4	11.8	780	22.3	6.8
768	22.3	6.7	894	21.5	8.5	1042	21.6	3.5
960	22.7	4.2	1140	21.1	10.2	1275	21.0	3.0
All loads	22.9	7.2	All loads	21.6	10.1	All loads	21.6	4.9

[a] Mechanical efficiency calculated from gross oxygen cost during effort, less predicted basal metabolism of 0.67 kcal/m² of body surface, assuming a constant energy equivalent of 5 kcal per litre of oxygen. Data for test subjects averaged over 5 days.

in general agreement with previous data for laboratory subjects (Shephard, 1967): maximum efficiency was seen at a moderate rate of stepping (90 paces/min), and minimum efficiency at the fastest rate. As in the previous series, the variability of data was least in the middle range of work-loads; however, the efficiency of the present group of test subjects varied more than that of the laboratory group, both before and after performance of maximum exercise.

Corresponding figures for the bicycle ergometer are presented in Table 4. The greatest efficiency was again seen at the second work-load, but the change in efficiency with work-load was less than that for the step test. Inter-individual variations in efficiency were greater at low than at high work-loads. The test subjects were initially more variable in their efficiency than the laboratory group, but this difference did not persist after experience had been gained through maximum exercise.

There was some tendency for efficiency to improve with repetition of a given form of exercise (Table 5). However, the change produced by a week of submaximal testing was relatively small (not more than a 3%–4% decrease in oxygen cost for either step or bicycle exercise).

The work performed during treadmill running could not be measured accurately, and it was thus more difficult to assess changes in efficiency. However, we did note a 7% decrease in oxygen consumption for a given treadmill speed and gradient, presumably due to learning, over the week of testing.

The prediction of maximum oxygen intake

Some widely used procedures for the prediction of maximum oxygen intake are: (1) linear extrapolation of four submaximum measurements of pulse rate and oxygen consumption to a predicted maximum pulse rate (Maritz et al., 1961); (2) the use of a nomogram or formula based on similar measurements at one intensity of effort (Åstrand & Ryhming, 1954; Von Döbeln et al., 1967); or (3) at two intensities of effort (Margaria et al., 1965). Results

TABLE 5

CHANGE IN EFFICIENCY OF EXERCISE FROM DAY TO DAY, WITH REPETITION OF TEST PROCEDURE, EXPRESSED AS MEAN MECHANICAL EFFICIENCY [a] AND MEAN COEFFICIENT OF VARIATION (%), AVERAGED OVER 4 SUBMAXIMAL WORK-LOADS

Days	Step test		Bicycle test	
	Mean efficiency (%)	Coeff. of variation (%)	Mean efficiency (%)	Coeff. of variation (%)
1, 6, 21	15.7	11.6	21.1	9.8
2, 7, 22	15.7	12.6	21.4	10.1
3, 8, 23	15.9	11.4	22.0	11.5
4, 8, 24	15.8	13.2	21.8	11.1
5, 10, 25	16.1	11.3	21.9	9.3

[a] Mechanical efficiency calculated from gross oxygen cost during effort, less predicted basal metabolism of 0.67 kcal/m² of body surface, assuming a constant energy equivalent of 5 kcal per litre of oxygen. Data for 24 test subjects.

TABLE 6

COMPARISON OF 4 PROCEDURES FOR PREDICTION OF MAXIMUM OXYGEN INTAKE (litres/min STPD) [a]

	Åstrand nomogram	Von Döbeln formula	Margaria nomogram	Maritz extrapolation
"Naïve" subjects (days 1 and 6)				
Step	−0.18±0.46	—	−0.09±0.39	−0.03±0.36
Bicycle	+0.30±0.31	−0.03±0.34	+0.18±0.27	+0.19±0.28
Treadmill	−0.27±0.37	—	−0.35±0.67	−0.17±0.57
Subjects after 5 days submaximal tests				
Step	+0.16±0.25	—	+0.12±0.28	+0.12±0.28
Bicycle	+0.33±0.35	−0.02±0.34	+0.13±0.35	+0.18±0.34
Treadmill	−0.04±0.39	—	−0.39±0.61	−0.22±0.44
Subjects after 4 days maximal tests				
Step	+0.25±0.32	—	+0.10±0.42	+0.10±0.19
Bicycle	+0.48±0.35	−0.11±0.32	+0.07±0.46	+0.15±0.43
Treadmill	+0.29±0.40	—	0.00±0.49	+0.28±0.51

[a] Results expressed as mean and standard deviation of departures from measured maximum intake procedure. The calculations are based on the formula of Margaria et al. (1965) and relate to the same range of pulse rates as permitted in the nomogram. However, the height of the present step is less and the rate of stepping correspondingly greater than that used by Margaria and his colleagues.

derived from these procedures are compared in Table 6. Individual values have been expressed as departures from the measured maximum oxygen intake. In " naïve " subjects, who had no previous experience of the given form of laboratory exercise (data from Days 1 and 6), figures from the step and treadmill tests underestimated the true maximum oxygen intake by 5%–10%, presumably because the pulse rate was increased somewhat by anxiety. The systematic error was somewhat less for the Von Döbeln formula and for the Maritz extrapolation; however, the scatter about the systematic error was similar for all forms of extrapolation.

As the subjects became habituated to a given task, the systematic error of prediction changed from a negative to a positive sign, and in the case of the bicycle ergometer (where initial anxiety was less marked) the systematic error for 3 of the 4 prediction methods was positive from the first trial of a given mode of exercise.

Use of a progressive test

Despite the relatively brief rest periods between testing, a series of 4 discontinuous tests occupied subjects for more than 1 hour. In many field situations, such a protracted series of observations is not possible for either the subject or the experimenter. Accordingly we examined the possibility of obtaining similar information from a continuous and progressive form of submaximal test. Comparison between the progressive and discontinuous tests has been based on the procedure most applicable to all 3 modes of exercise (the Maritz extrapolation). The predicted maximum oxygen intake for Day 4, 9, or 24 has been compared with the mean of observations for Days 3 and 5, 8 and 10, or 23 and 25 respectively (Table 7).

Closely similar predictions of maximum oxygen intake were obtained from the continuous and discontinuous tests. The use of a continuous test did not give rise to systematic error nor did it increase the scatter of observations.

Practical considerations

An adequate electrocardiogram during exercise is important to both the safety and the diagnostic value of the test. The quality of the electrocardiogram during the 3 types of exercise was thus eva-

TABLE 7

COMPARISON OF DISCONTINUOUS AND CONTINUOUS TESTS FOR PREDICTION OF MAXIMUM OXYGEN INTAKE (litres/min STPD) [a]

	Step test		Bicycle test		Treadmill test	
	Mean	SD	Mean	SD	Mean	SD
Discontinuous (mean of days 3 and 5, 8 and 10, or 23 and 25)	3.75	±0.87	3.57	±0.81	3.83	±0.90
Continuous (day 4, 9 or 24)	3.73	±0.93	3.64	±0.86	3.79	±0.89
Difference	−0.013	±0.34	+0.069	±0.29	−0.043	±0.61

[a] Results are in each case based on linear extrapolation to predicted maximum pulse rate. Data for 24 subjects.

luated in terms of baseline stability, muscle noise, and movement artefacts (Table 8). Baseline stability was similar for the 3 procedures. Muscle noise was absent in the step and treadmill experiments, but was quite marked in some bicycle ergometer tests, particularly at high work-loads. Gross movement artefacts were a problem in some treadmill tests; several subjects showed gross (>0.5 mV) deflexions of the baseline coincident with running.

Several other practical problems were encountered. Complicated techniques, such as the measurement of cardiac output by the rebreathing method, were very difficult to perform during stepping. Some subjects complained strongly of discomfort from the saddle after four 5-min periods of exercise on the bicycle ergometer. It also proved rather difficult to select 4 evenly spaced work-loads for the treadmill. Although none of these was a major problem, all deserve consideration in the choice of test procedure in any given situation.

DISCUSSION

Physiological differences between the 3 forms of exercise

Differences in physiological response to the 3 forms of leg exercise were slight at moderate work-loads and seemed related largely to the extent of the anxiety induced by the test procedure. However, the earlier and greater accumulation of lactate, with a concomitant increase of exercise ventilation, indicates the existence of more fundamental differences in the response to heavy work on the bicycle ergometer.

Lactate could accumulate from: (1) delayed adjustment of blood flow to muscle requirements; (2) general circulatory inadequacy; or (3) a specific impairment of flow by muscle contraction. The first mechanism would give a peak blood concentration after 1-2 min of exercise, and this should be largely dissipated after 5 min of continuing exercise; further,

TABLE 8

QUALITY OF THE ELECTROCARDIOGRAM RECORD WITH 3 FORMS OF SUBMAXIMAL EXERCISE [a]

	Step test			Bicycle ergometer			Treadmill		
	Good	Fair	Poor	Good	Fair	Poor	Good	Fair	Poor
Baseline stability	13	10	1	12	11	1	17	7	0
Muscle noise	24	0	0	9	12	3	24	0	0
Movement artefacts	13	11	0	14	8	2	12	7	5

[a] The main positive finding is that in the majority of subjects good electrocardiogram records can be obtained with all 3 modes of exercise. Since the electrodes were fitted by different personnel for the 3 types of test, it is conceivable (but unlikely) that differences of technique contributed to the differing frequency of baseline instability and muscle noise.

there is no obvious reason why the circulatory transient response should differ for bicycle, step, and treadmill exercise. In the classic paper on anaerobic metabolism, Margaria et al. (1933) apparently held the view that accumulation of lactate due to general circulatory inadequacy began at loads greater than two-thirds of aerobic power; however, more recent evidence (Saiki et al., 1967) suggests that accumulation does not occur until the subject is exercising at very close to his full aerobic power. Thus, although the maximum stroke volume and cardiac output are somewhat less during bicycle than during treadmill exercise (Shephard et al., 1968), circulatory inadequacies cannot explain the difference in anaerobic metabolism in the 2 forms of submaximal exercise. It must therefore be postulated that blood flow through certain specific muscle groups is impaired while they contract; Barcroft & Dornhorst (1948) found evidence of such an effect during rhythmic exercise, and from the local weakness and discomfort reported by the subjects, the site is probably the quadriceps muscle.

The development of a substantial local oxygen debt is an important theoretical argument against use of the bicycle ergometer for submaximal exercise. The traditional method of calculating efficiency is prejudiced and the meaning that can be attached to measurements of pulse rate and respiratory minute-volume at a given level of oxygen consumption is much more dubious.

Choice of exercise

Both physiological and practical considerations influence the choice of procedures for submaximal exercise. The treadmill, despite its suitability for maximum exercise (Shephard et al., 1968), seems the least desirable of the 3 submaximal tests. The apparatus is bulky, noisy, expensive, and requires careful maintenance. The task is unfamiliar and somewhat frightening to the average subject, and the initial pulse-rate response varies with both habituation (diminishing anxiety) and learning (increasing efficiency). It is not easy to select suitably spaced work-loads, and the work performed cannot be measured with any precision. The quality of the electrocardiogram is often poor; and, if the condition of the subject demands rest, time is needed to stop the treadmill and transfer the patient to a couch.

The main advantages of the bicycle ergometer are that habituation and learning are slight, and the subject's arms are freely available for such procedures as catherization or measurement of blood pressure. The mechanical efficiency of effort and the work performed are also known fairly precisely. On the other hand, careful calibration of the apparatus is necessary, and a good-quality bicycle ergometer is relatively expensive. The electrocardiogram may be distorted by muscle noise, and it is not easy for a subject encumbered by leads to dismount in an emergency. However, the most important objection to use of the bicycle ergometer is the extent of anaerobiosis during moderate work.

A 9-in (23-cm) step is familiar to most subjects, but some anxiety may arise from tripping at rapid rates of ascent. The apparatus is cheap and portable, and requires no maintenance, calibration, or electricity supply. The mechanical efficiency of effort is a little more variable than on the bicycle ergometer, but if the technique is carried out carefully, the work performed can be estimated quite accurately. The main disadvantage of the step test is a continuous movement of the arms and head, thus making some physiological measurements difficult.

It is difficult to propose a single test that is suited to all needs. In the field situation, a simple stepping procedure seems most suitable, but if it is necessary to measure blood pressures or to catheterize the subject then a bicycle ergometer will be needed.

Pattern of testing

The progressive form of test, with an increase of the work-load at the end of every third minute, proved very satisfactory on the present group of healthy young adults; however, it is less certain how well it would work on patients with an increased circulation time; it is desirable to keep the total duration of exercise as short as possible, since there is a slow but progressive rise of pulse rate throughout exercise due to the increase in deep body temperature (Shephard, 1967). This again makes it difficult to devise a single recommendation for all sorts and conditions of men. A progressive pattern of test should certainly be used, but in subjects with some circulatory delay, a sequence of three 4-min loadings may be preferable to four 3-min loadings (WHO Meeting on Exercise Tests in Relation to Cardiovascular Function, 1968).

Interpretation of results

Cotes (1966) has entered a strong plea for direct reporting of the findings during submaximal exercise on the grounds that no new information is added to the data by extrapolation. However, direct reporting suffers from two deficiencies. First, the maximum pulse rate varies greatly with age: if a pulse rate of 145/min is reported at a fixed oxygen consumption of 1.5 litres/min, the significance of this observation will be very different in the young and in the elderly. Second, subjects of a given age differ widely in their aerobic power: an oxygen consumption of 1.5 litres/min is beyond the reach of some older sedentary subjects (Brown & Shephard, 1967), but is a relatively light load for others of a more athletic disposition. For these reasons, we prefer the prediction of maximum oxygen intake to the direct reporting of results.

As might be anticipated, there is a slight improvement in the precision of prediction as the number of observations used is increased from 1 pair to 2 or 4 pairs (Table 6). However, for many purposes the gain in precision is not enough to justify the additional measurements and the labour or computer time involved in fitting a linear regression. Results from the new formula of Von Döbeln et al. (1967) are encouraging; and although at present their procedure is only applicable to bicycle ergometer data, it might be worth while extending it to include step test predictions. The theoretical basis of the formula is extremely sophisticated, but in practice, its new feature is the tacit assumption of a mechanical efficiency that decreases with an increase of maximum oxygen intake. It seems unlikely that the true mechanical efficiency is lower in the more athletic, and so presumably their anaerobic metabolism is less at a given submaximal load, and the calculated mechanical efficiency is lower because it is closer to their true mechanical efficiency.

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RÉSUMÉ

Un groupe de travail international a comparé les résultats des épreuves sous-maximales sur marches, sur bicyclette ergométrique et sur tapis roulant, auxquelles ont été soumis 24 jeunes Canadiens du sexe masculin. Il a constaté que l'accoutumance (diminution, pour une charge donnée, de la fréquence des pulsations, du fait d'une réduction de l'anxiété) atteignait un maximum sur le tapis roulant et était la plus faible sur la bicyclette ergométrique. L'entraînement (augmentation du rendement pour une charge donnée) parvenait à une valeur maximale lors de l'épreuve sur tapis roulant, et présentait un niveau égal au cours des épreuves sur marches et sur bicyclette ergométrique. Le rendement, aux taux d'effort élevés, variait moins, d'un individu à l'autre, dans l'exercice sur bicyclette que pendant la montée de marches. Il a fallu une charge moins élevée sur la bicyclette que sur les marches ou le tapis roulant pour que s'instaure le métabolisme anaérobie, et l'on a observé que ce dernier s'accompagnait d'une hyperventilation disproportionnée. Les quatre méthodes utilisées pour mesurer la consommation maximale d'oxygène d'après la fréquence des pulsations et la consommation d'oxygène au cours des épreuves sous-maximales ont fourni des résultats similaires. On a obtenu les mêmes chiffres lorsque les épreuves comportaient une série continue de charges croissantes (augmentées toutes les 3 minutes) ou une série discontinue de quatre exercices.

Pour les expériences pratiquées sur le terrain, on recommande d'utiliser l'épreuve des marches selon la technique continue; pour les expériences en laboratoire où le bras doit rester immobile pour permettre les contrôles physiologiques, on se servira de la bicyclette ergométrique avec une série continue de charges croissantes.

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