A SIMPLE STANDARD EXERCISE TEST AND ITS USE FOR MEASURING EXERTION DYSPNOEA

BY

P. HUGH-JONES, M.D., M.R.C.P.

With the assistance of A. V. LAMBERT

(From the Medical Research Council Pneumoconiosis Unit, Llandough Hospital, Cardiff)

In the management and study of patients who have their exercise capacity reduced by heart or lung disease some way of estimating the degree of breathlessness on exertion is often required. Only a rough estimate can be got from the patients' descriptions of their symptoms, which, although helpful in diagnosis, are inadequate for many purposes. An objective and more precise estimate is needed for a reliable judgment of the effects of treatment or for comparing one method of treatment with another, for assessing the patient's capacity for physical work during rehabilitation, for awarding compensation in industrial pulmonary disease, and for many types of survey investigation.

For these purposes various exercise-tolerance tests have been devised. A type of test which is simple, and commonly used, is to get the patient to step up and down from a stool or chair and, at the end of a period of exercise, to assess his response subjectively in terms of " breathlessness," or objectively by counting the respiratory and pulse rates. This sort of test has been criticized by a number of workers (Brittingham and White, 1922 ; Wahlund, 1948 ; Renner, 1951). There are two main objections to it as it is usually done:

1. The amount of exercise is not measured. It depends on the rate and time of stepping and on the height of the stool or chair, and also varies individually with the weight of the patient.
2. The ventilatory cost of the exercise is not measured. This cannot be measured by counting the respiratory rate, because the depth of breathing may not remain constant, while the recovery pulse is variable even in normal subjects and is not well related to ventilation (Cotton *et al.*, 1916 ; Mann, 1918 ; Reisinger, 1938 ; Belayew, 1948 ; N. P. V. Lundgren, 1951, personal communication), although some observers contend that the pulse rate gives useful information concerning the state of the circulation (Meakins and Gunson, 1916 ; Master and Oppenheimer, 1929).

A known amount of exercise can be given by a bicycle ergometer or a treadmill, but these machines are usually impracticable for clinical use owing to their complexity and immobility. Thus various modifications of the simple step-test have been suggested in attempts to make it objective and precise. Some of these, in which the subject's maximum effort is sought (Lundgren, 1949 ; Behnke, 1942) may be useful as efficiency tests in fit subjects but are too distressing for ill patients, while others (Nylin, 1933, 1936 ; Master, 1935), although they are submaximal tests and are designed to give quantitative results, have other drawbacks. Nylin's test requires a special stairway, and, although Master's test is simple, the results merely show whether a patient's exercise tolerance is " within average figures," the exact response being obtainable only by trial and error in repeat testing. Neither of these tests measures breathlessness.

In this paper, modifications to the step-test are described which allow it to be used for giving a standardized and known amount of exercise without appreciably impairing its simplicity. The response to it is measured in terms appropriate for the quantitative expression of breathlessness.

Principles of the Test

The exercise is standardized by arranging that every patient does the same amount of mechanical work with approximately the same efficiency. The ventilatory cost of the work is found by measuring the volume of air exhaled per minute for an appropriate time before, during, and after the exercise.

In arranging that each subject does a standard amount of exercise regardless of his weight the test resembles that of exercise with a bicycle ergometer. It differs from a step-test used by Baldwin, Cournand, and Richards (1948) in which the exercise is standard only " in that each subject performs a standard number of steps within one minute of time." It may be asked: Why use standard exercise for all patients when they vary in weight and have to carry that weight about ? The answer depends upon what is required of an exercise test. If only a specific function such as a subject's ability to go up steps or to walk at a given rate is to be assessed, then clearly a direct test of this function is to be preferred to a standard test. Standard exercise is useful as a general test in that it is not specific to any particular task. Further, standard exercise is preferable for the assessment of change in ventilatory efficiency over a period of time—for example, in assessing the effects of treating heart failure, or when reassessing a patient for compensation, etc.—otherwise any change observed may merely be a reflection of a difference in the patient's weight. Lastly, if in a group of subjects one wants to know whether variations in their ventilation may be due to disturbed cardiopulmonary function a standardized test must be used ; or, again, the variations may simply reflect differences in their weights.

Apparatus and Method

Standardizing the Exercise.—Since the external mechanical work performed in a step-test is a product of the patient's weight and the height and rate of stepping, it is evident that altering either the height or the rate of stepping can compensate for differences in weight between one patient and another and so keep the amount of work constant. However, the range of variation in weight that is commonly encountered is such that if stepping rate only were altered the lightest of subjects would have to step so quickly and the heaviest so slowly that the comparison between them would not be fair, since their physiological efficiency would not be comparable. Similarly, unfair comparisons might be made if only the height of step were changed. But if both height and rate

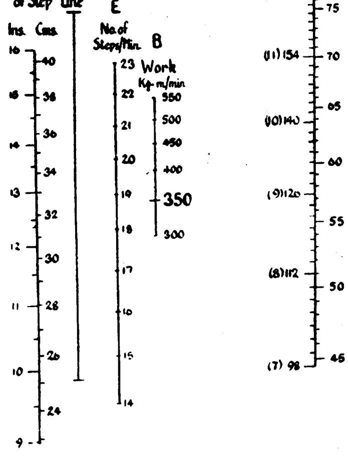

FIG. 1.—Nomogram for determining appropriate combinations of height and rate of stepping so that all subjects do the same amount of work in the step-test independent of their weight.

are altered to compensate for weight variations, large adjustments of either can be avoided. The appropriate height and rate of stepping are quickly found without calculation by using the nomogram reproduced in Fig. 1.*

The nomogram is used by placing a ruler on scale A at a point corresponding to the weight of the subject, and the ruler is then adjusted so that it passes through the amount of work chosen on scale B. The place where it intersects the reference line C is marked. The ruler is then laid across the scales D and E in any position, provided that its edge passes through the point marked on line C. The readings thus obtained from D and E will give a combination of height and rate of stepping which will ensure that the subject performs the chosen amount of work.

In preparing the nomogram scale E was limited so that its extremes were within the flat-topped part of the well-known curves relating rate of muscular contraction and physiological efficiency (Lupton, 1923; Garry and Wishart, 1931). Scale D was limited so as to avoid large changes in knee-angle and hence in available leg-thrust (Hugh-Jones, 1947). If the ruler is kept reasonably horizontal through the point found on scale C, any changes in physiological efficiency between one subject and another due to change in height and rate of stepping will be minimized. It has been found experimentally that, even when the extremes of the height and rate lines are used, efficiency is not appreciably affected (see the results of the appraisal of the test below).

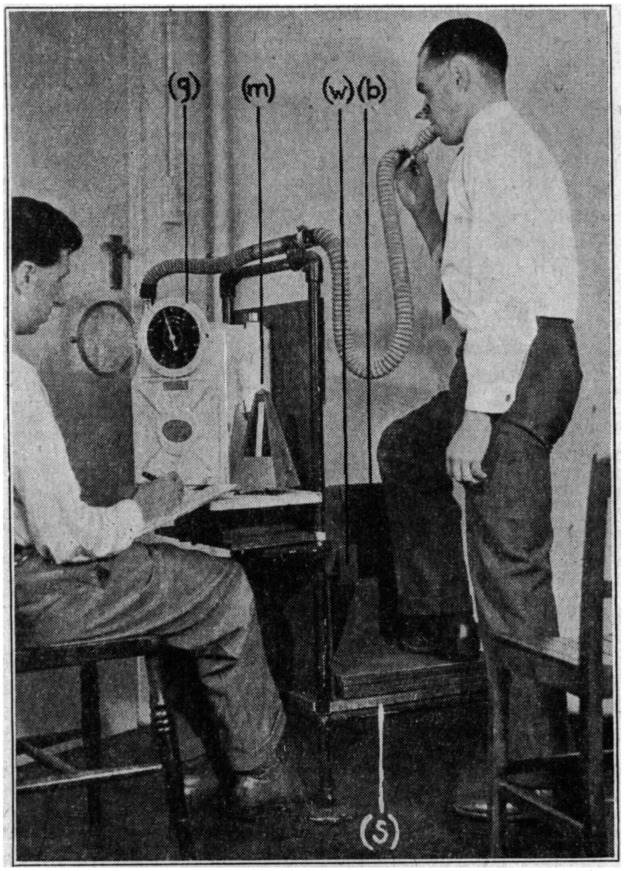

FIG. 2.—The apparatus. b=½-in. (1.25 cm.) boards for altering height of step. g=Gas-meter. m=Metronome. s=Stand. (Note: It is convenient to fit a sloping bar of wood (w) to the stand, as shown, and to slot the boards (b) in the appropriate place to fit against this bar. The boards can then only be placed on the step in a definite order so that each can be marked with the height of step formed when it is at the top of the pile.)

Equipment.—Three simple pieces of equipment are used for the test (Fig. 2): (1) a metronome for controlling the rate of stepping; (2) a low rigid stand or platform, about 15 by 12 by 9 in. (38 by 30 by 22.8 cm.) high, whose height can be altered in ½-in. (1.25-cm.) increments by placing the appropriate number of ½-in. (1.25-cm.) boards on it; and (3) a low-resistance domestic type of gas-meter fixed to the platform at about elbow-height standing. This meter faces away from the patient using the step. It is modified by replacing its multiple small dials by a single large dial and pointer which is so geared that one revolution corresponds to 50 litres of gas passing through the meter, the dial being calibrated so that it can be read to the nearest half-litre. The pointer can be reset to zero manually. A mouthpiece and two-way valve are connected to the gas-meter by corrugated tubing from the valve outlet; the patient holds the valve in the hand while using the mouthpiece.

Procedure.—The patient is weighed and the step and metronome are each adjusted to the values selected from the nomogram. It is convenient to set the metronome at four times the stepping rate so that when exercise starts the left foot is raised on to the step in time with one click of the metronome, the right foot is then brought to it on the second click, the left foot returned to the ground on the third, and the right foot returned on the fourth, and so on. Using the metronome in this way makes it easier for the patient to keep time. While the test is being explained and demonstrated to him the patient rests in a chair. He puts on a nose-clip and gets used to breathing through the mouthpiece. The observer then records the cumulative readings of the gas-meter every half-minute for at least three minutes of rest. The metronome is started and the patient completes five minutes of exercise-stepping followed by about five minutes of recovery, during which he again sits at rest. During both the exercise and the recovery period the observer continues to record the half-minute meter readings until constancy in consecutive readings shows that recovery is complete.

Work-level Used.—For general purposes 350 kg.m./min. has been used for the five minutes of exercise. This level means that the exercise is not limited by muscle fatigue. It was chosen to provide enough exercise in fit subjects to provoke an accurately measurable ventilatory response, yet allowing the test to be completed by all but the most seriously disabled patients. Since the results can be expressed so that retesting at a lower level of work is unnecessary even if patients fail to complete the full five minutes of exercise (see below), this one work-level has been satisfactory. However, if only very seriously disabled patients were to be tested a lower level of work might be preferable.

Expression of the Results

In Fig. 3 the results of a typical exercise test in a normal subject are shown graphically in order to simplify description of the terms to be used. Differences between the successive cumulative readings of the gas-meter, which are the volumes of air exhaled in successive half-minute periods, have been plotted against time. The ventilation, which is constant at rest, increases during the first two or three minutes of exercise until a "steady state" is reached. When the exercise ceases the ventilation returns to the resting level. In patients who complete the exercise (the majority), with the venti-

---

*Full-size photographic copies of the nomogram (10 by 8 in.—25 by 20 cm.) are available on application to the Director, M.R.C. Pneumoconiosis Research Unit, Llandough Hospital, near Cardiff. Price 2s.

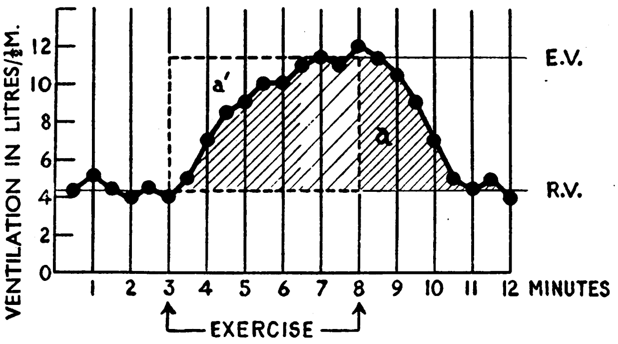

FIG. 3.—A typical result of the exercise test in a normal subject shown graphically to facilitate description of the terms used (see text). R.V. = Resting ventilation (ordinate × 2, litres/minute). E.V. = Exercise ventilation at a steady state (ordinate × 2, litres/minute). a = Area of replacement of ventilatory debt. (a′ is an equivalent area.) Shaded area = Excess volume of air used as a result of the exercise (E.E.V.) Standardized excess ventilation $(\text{S.E.V.}) = \frac{(\text{E.E.V.})}{\text{Time of Ex.}}$ i.e., average ventilatory cost (litres/min.) for each 350 kg.-m. of work done. Standardized ventilation (S.V.) = S.E.V. + R.V.

lation at a steady state, the "exercise ventilation" (E.V.) can be simply taken as a measure of the ventilation resulting from the exercise.

A few patients cannot, or will not, complete the full five minutes of exercise, and in these cases the E.V. is not an appropriate measure. However, in all patients the ventilatory cost of whatever work is done is the total increment of ventilatory volume during exercise and recovery above the initial resting level. This value, the "exercise excess volume" (E.E.V.), is represented by the area shaded in Fig. 3. Divided by the time of exercise it represents the average ventilatory cost of each 350 kilogram–metres (kg.-m.) of work which is completed. This average value is called the "standardized excess ventilation" (S.E.V.). The sum of the S.E.V. and the resting ventilation (which is comparable with the E.V.) is called the "standardized ventilation" (S.V.); it is an appropriate measure of ventilatory cost in all cases (see paragraph on the relation between the S.V. and E.V. below).

In practice the test results need not be graphed. The successive meter readings are recorded, together with their differences. The E.V. is then taken as the average difference in meter readings during the last three or four half-minutes of exercise over which the differences are approximately constant. This value is doubled, and so expressed in litres/minute. The S.V. is calculated as follows: the excess ventilatory volume of air used on account of the exercise (E.E.V.) is found by subtracting from the final meter reading the volume of air which would have been exhaled at rest during a corresponding period of time (the latter being got from the meter-reading at the end of the initial period of three minutes' rest by proportion); this volume is standardized by dividing by the time of exercise, and so expressed in litres/minute, and then added to the resting ventilation (R.V.). All gas volumes are expressed as saturated with water vapour at body temperature by multiplying by the appropriate factor given in Table I.*

Thus, in summary, the results obtained from the cumulative readings of the gas-meter as measures of the ventilatory cost of the work are: (1) the S.V., which is the sum of the S.E.V. and R.V. and is appropriate in all cases; and (2) E.V., which is simpler but appropriate only when the patient completes the full five minutes of exercise.

TABLE I.—*Factors by Which Gas Measurements Recorded at Varying Room Temperatures are Multiplied for Correction to Body Temperature*

Temp. °C.	Factor	Temp. °C.	Factor	Temp. °C.	Factor
16 ..	1·119	21 ..	1·090	25 ..	1·069
17 ..	1·111	22 ..	1·085	26 ..	1·063
18 ..	1·107	23 ..	1·080	27 ..	1·057
19 ..	1·101	24 ..	1·074	28 ..	1·051
20 ..	1·097				

Relation Between the Standardized and Exercise Ventilation

The relation between the S.V. and the E.V. can be deduced from Fig. 3. Since the ventilatory debt, which accumulates at the beginning of exercise before a steady state is reached, is repaid quantitatively after the exercise ceases (Hill and Lupton, 1923), the area (a) can be represented by an equivalent area (a′), so that the excess volume of air used on account of the exercise (E.E.V.) is represented by the area outlined in dots. Hence in subjects who achieve a "steady state" the S.V. (which is represented by any one of the five rectangles between the minute abscissae during the exercise period and the upper dotted line of the E.E.V. rectangle) should be identical with the E.V. The agreement between the two is found to be very close in practice (see Fig. 5 and discussion of results).

But if a subject stops the exercise before a steady state is reached the S.V. will then be greater than any level of ventilation actually achieved. Thus, if the patient in Fig. 3 had elected to stop the exercise after only two minutes, when his ventilation was 9 litres in the half-minute, the

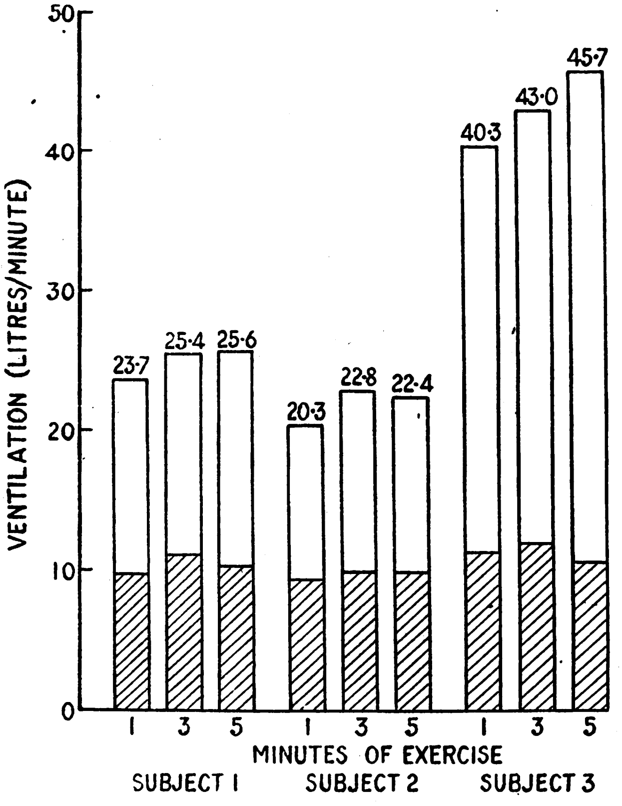

FIG. 4.—Results of standard exercise tests on each of two normal subjects and one with advanced emphysema (subject 3). All subjects did three tests with respectively one, three, and five minutes of exercise. Shaded rectangle = Resting ventilation (R.V.). Clear rectangle = Standardized excess ventilation (S.E.V.). Standardized ventilation (S.V.)—that is, S.E.V. + R.V.—is given in figures above each rectangle.

---

*It is assumed that the gas in the meter is at room temperature. This assumption is not quite true, but correcting for variations in room temperature in this way leads to negligible error.

total ventilation in excess of the resting level would still represent the ventilation due to the exercise (though in this case only a total of 700 kg.-m. instead of the full 1,750 kg.-m.—350 kg.-m.×5 minutes), so that, when standardized, the ventilatory rate (or S.V.) would be the same as before.

When the level of exercise is an "overload," in a seriously disabled patient, the same argument applies: the ventilatory debt continues to increase the longer the exercise goes on; the patient is forced to stop, and pays back the debt by spreading an increase of ventilation over a number of minutes during recovery. The S.V. then represents a ventilatory rate greater than that which could be maintained or even achieved by the patient, for if this were not so a "steady state" rather than further debt could have been reached by continuance of the exercise.

Since the S.V. is theoretically independent of the time of exercise, why should we not be satisfied with less than five minutes of exercise? The reason is that small increments of ventilation over the resting level are difficult to detect. This point is demonstrated, and the above theoretical discussion justified, by an experiment in which two normal subjects and one subject with advanced emphysema, who could only just manage five minutes of exercise, performed three tests at the standard rate of 350 kg.-m./minute, but for one, three, and five minutes of exercise respectively. The results are shown in Fig. 4. It will be seen that the S.V. is reasonably independent of the time of exercise, though it tends to be smaller the shorter the exercise, so that when only one minute of exercise is performed it is an underestimate by about 10% of the value for five minutes' exercise. At three minutes there is an underestimate (5%) only in subject 3. Thus the standardized ventilation of subjects so disabled as to be unable to do more than three minutes of exercise at the low rate used in the test (a small minority in practice) is likely to be an underestimate of their ventilatory cost, which in these cases may be very large.

The underestimate in very short periods of exercise probably arises because the shorter the exercise the greater the relative contribution of the recovery ventilation to the total ventilatory cost, and recovery ventilation cannot be assessed very precisely because small elevations of ventilation over the resting level will be missed and the recovery period will then not be fully recorded.

There is no purpose is prolonging the exercise beyond five minutes, because any patient who is capable of achieving a steady state at the level of exercise used will have done so, and once this steady state has been achieved no greater precision will be obtained for the standardized excess ventilation.

Validity of the Test

The nomogram enables all subjects to be given a constant amount of external mechanical work, but is it true that subjects do a constant amount of physiological work? In other words, is the physiological efficiency the same over different portions of the nomogram? In order to determine this and to find the repeatability of the test, an experiment was designed as shown in Table II.

Three subjects, who were chosen to cover a fairly wide range in weights, performed the test daily during two periods of three days each. On each day the test was done three times (at 10 a.m., 2 p.m., and 4 p.m.) with different step-heights representing high, medium, and low values on the height scale of the nomogram, each height being used with the appropriate stepping rate to give the standard amount of work. The experiment was randomized as shown in Table II. The results of the experiment are given only in terms of the exercise ventilation, as all subjects completed the full five minutes of exercise and reached a steady state.

An analysis of these results is shown in Table III, in which the average values of the E.V. for comparable groups of results are given.

It will be seen from Table III that the method of standardizing the work is fully justified experimentally, since high, medium, and low heights of step, combined from the nomogram with appropriate slow, medium, and fast stepping rates respectively, lead to almost identical exercise ventilation rates. This experimental demonstration of the physiological validity of the nomogram confirms the conclusions of Passmore and Thomson (1950) that "stepping is a muscular movement with a very broad optimum of efficiency both as regards rate of stepping and height of step." They found a wide maximum of efficiency at rates between 14 and 18 steps a minute on a 10-in. (25-cm.) step.

TABLE II.—*The Design and Results of a Randomized Experiment Used to Determine the Validity and Repeatability of the Method of Giving a Constant and Known Amount of Exercise to Subjects of Different Weights When Performing the Step-test*

	Weight	Step Height		
		Low	Med.	High
	st. (kg.)	in. (cm.)	in. (cm.)	in. (cm.)
Subject 1 ..	14·04 (88·9)	9 (22·9)	10 (25·4)	11 (27·9)
,, 2 ..	10·04 (63·5)	10½ (26·7)	11½ (29·2)	12½ (31·7)
,, 3 ..	9·00 (57·15)	12 (30·4)	13 (32·9)	14 (35·4)

Date		Subject 1			Subject 2			Subject 3		
		High	Med.	Low	High	Med.	Low	High	Med.	Low
8/2/50	Time	2 p.m.	10 a.m.	4 p.m.	4 p.m.	2 p.m.	10 a m.	10 a m.	4 p.m.	2 p.m.
	E.V.	29·2	26·3	25·0	23·0	25·0	25·3	25·2	23·0	24·0
9/2/50	Time	10 a.m.	4 p.m.	2 p.m.	2 p.m.	10 a.m.	4 p.m.	4 p.m.	2 p.m.	10 a.m.
	E.V.	27·8	26·2	27·3	24·8	24·0	22·2	18·6	20·8	21·8
10/2/50	Time	4 p.m.	2 p.m.	10 a.m.	10 a m.	4 p.m.	2 p m.	2 p.m.	10 a.m.	4 p m.
	E.V.	27·0	25·3	26·6	22·8	21·4	23·1	19·8	19·2	22·2
13/2/50	Time	4 p.m.	2 p.m.	10 a.m.	2 p.m.	10 a m.	4 p.m.	10 a.m.	4 p.m.	2 p.m.
	E.V.	29·6	28·3	28·3	24·0	24·0	25·0	20·1	24·0	23·6
14/2/50	Time	2 p.m.	10 a.m.	4 p.m.	10 a.m.	4 p.m.	2 p m.	4 p.m.	2 p.m.	10 a.m.
	E.V.	29·4	27·4	27·3	24·1	26·2	25·1	20·3	21·2	21·9
15/2/50	Time	10 a.m.	4 p.m.	2 p m.	4 p.m.	2 p.m.	10 a.m.	2 p m.	10 a.m.	4 p.m.
	E.V.	28·4	28·4	29·4	24·0	25·1	25·1	20·7	21·8	21·8

It is also seen from Table III that the test provides an objective measure of ventilatory cost which is highly repeatable, not being materially affected by the time of day or by variation between one day and another, though a full analysis of variance on the data showed the variance between days to be statistically significant.

TABLE III.—*An Analysis of the Results in Table II*

Step Height	High	Medium	Low	
Av. E.V.	24·4	24·3	24·7	S.E. = 0·29
Time of day	10 a.m.	2 p.m.	4 p.m.	
Av. E.V.	24·5	24·8	24·2	S.E. = 0·29
Day of test	8/2/50	9/2/50	10/2/50	S.E. = 0·41
Av. E.V.	25.1	23·7	23·0	
Day of test	13/2/50	14/2/50	15/2/50	
Av. E.V.	25·2	24·8	25·0	

Measurement of Breathlessness

We still have to relate the ventilatory cost of the standard exercise to the symptom of exertion dyspnoea. It is generally agreed that "breathlessness" is noticed with increasing severity the more nearly a subject's ventilation approaches the maximum of which he is capable. Thus to assess breathlessness on exertion the results of the exercise test must be related to the subject's maximum ventilation. The latter can be most conveniently measured on voluntary hyperventilation (Gray *et al.*, 1950, review the evidence for this), and it is then called the maximum breathing capacity (M.B.C.) or maximum voluntary ventilation (M.V.V.). Thus the relation between a patient's ventilation at a given state of exertion to the M.V.V. has been called a "dyspnoeic index": for if a patient's ventilation is only, say, 20% of his maximum, he is not very breathless, while if it is, say, 80%, then he is severely dyspnoeic. This, or a similar index, has been widely used by previous workers—for example, Kaltreider and McCann, 1937; Hannon, 1945; Warring, 1949; Baldwin *et al.*, 1949a, 1949b; Matheson and Gray, 1950; Pachner, 1950).

The Two Indices of Dyspnoea

By relating the results of the standard exercise test to the patient's M.V.V., two indices of dyspnoea are obtained:

The first dyspnoeic index (D.I.$_1$) is that used by previous workers:

$$\frac{\text{E.V.} \times 100}{\text{M.V.V.}}$$

The second index (D.I.$_2$) is the relation not of the exercise but of the standardized ventilation to the maximum:

$$\frac{\text{S.V.} \times 100}{\text{M.V.V.}}$$

The relation between these two indices is shown in Fig. 5, which is a scatter diagram of the results obtained from 228 subjects ranging from young normal men to men with severe pneumoconiosis, emphysema, and heart failure, so that all degrees of breathlessness on exertion are covered.

The value used for the patient's M.V.V. was the same in each index and was measured independently of the exercise test, all measurements being corrected to body temperature. The apparatus used has already been described (Gilson and Hugh-Jones, 1948–9).

It will be seen from Fig. 5 that in all patients who completed the full five minutes of exercise (185 out of the 228, shown as dots) the two indices agree very closely, the continuous line in the figure representing perfect agreement. This means, since the denominator of both indices is the same in any one patient, that the E.V. and S.V. are the same provided a steady state is reached; we have seen that this should be so theoretically.

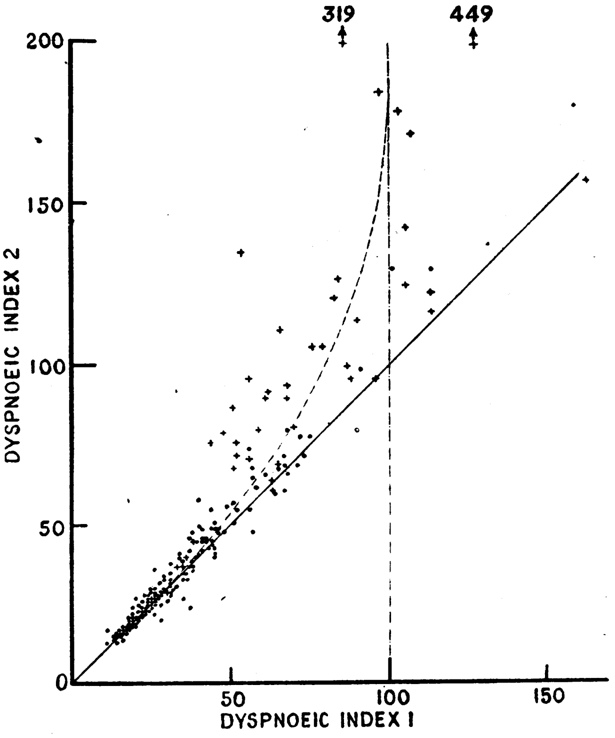

FIG. 5.—Scatter diagram showing the relation of the two alternative indices of dyspnoea obtained from the exercise test and measurements of the maximum voluntary ventilation (M.V.V.) on 228 subjects who covered a wide range of dyspnoea on exertion $(\text{D.I.}_1 = \frac{\text{E.V.}}{\text{M.V.V.}} \times 100.\quad \text{D.I.}_2 = \frac{\text{S.V.}}{\text{M.V.V.}} \times 100)$.
(Note: only 193 points are shown on this diagram, since the points would be superimposed in 35 out of the 228 subjects.)

Consider now the first dyspnoeic index (abscissae). First of all, by definition, this should not exceed 100%, since the M.V.V. is taken to represent the patient's maximum possible ventilation (Gray *et al.*, 1950). In fact, 10 of the 219 cases show an index greater than this. In these cases either full co-operation was not obtained in recording the M.V.V. or in a few very disabled men an exercise overload may create greater hyperventilation than the patient can bring himself to achieve voluntarily: these 10 patients were all very disabled and only two completed the exercise. Secondly, in subjects who do not reach a steady state an index obtained by using the maximum level of ventilation as a substitute for the true E.V. at a steady rate is false, for this ventilation results from less exercise than that of other subjects.

Now, if we consider the alternative D.I.$_2$ (ordinates) it is evident that it may, and should, exceed 100% in a few cases. We have seen that very disabled subjects may spread a debt of ventilatory cost over a number of minutes which, when standardized by relating the total excess ventilation in exercise and recovery to the exercise time, gives a ventilatory *rate* (S.V.) greater than that of which they are capable.

It is probable that the subjects who failed to complete the five minutes of exercise and had a D.I.$_2$ of below about 80% in Fig. 5 could have completed it and reached a steady state had they been prepared to tolerate the feeling of dyspnoea, since an approximately equal number of such subjects did so. They would have increased their exercise ventilation, and their "$D.I._1$" would have been increased to the correct figure. In those who failed and in whom the S.V. was greater than that which could have possibly been replaced at a steady state because of their maximum ventilatory limit, the index exceeds 100%.

The broken line in Fig. 5, about which all the points scatter, has been inserted, since it may aid the concept of the ventilation on exercise being unable to exceed a limit set by the maximum ventilatory capacity (100% $D.I._1$). The continuous straight line of agreement between the indices means a steady state or "pay as you go"; the broken line represents a departure from this by stopping exercise as the limit of ventilation is approached and breathlessness becomes intolerable. A greater proportion of the ventilatory debt is then spread into the recovery period by those who fail, giving an S.V. increasingly large compared with the E.V. and hence an increasingly large $D.I._2$.

In summary: by comparing the S.V., instead of the E.V., with a subject's M.V.V. we obtain an index of dyspnoea ($D.I._2$) which is practically identical in all subjects who complete the 5 minutes' exercise with the index commonly used ($D.I._1$). The new index of dyspnoea has the advantage of being applicable even if the subject fails to complete the exercise, provided two or three minutes are done to give a reasonably reliable estimate of the S.V.; thus the necessity for repeat testing at different exercise levels is avoided. When the subject cannot achieve a steady state, at the exercise level used, the $D.I._2$ may exceed 100%.

Is the dyspnoeic index in practice related to the symptom of breathlessness? Kaltreider *et al.* (1937) found the usual index ($D.I._1$) to be well related to subjective dyspnoea. Baldwin *et al.* (1949a) found "a clear-cut correlation between the severity of dyspnoea as recorded in each patient's history" and their "breathing reserve" (which is the complement of the $D.I._1$—that is, $\frac{M.V.V. - E.V.}{M.V.V.} \times 100$) though subsequently Baldwin *et al.* (1949b) found the threshold of breathlessness on this index to be lower in cases of emphysema than in other patients. However, in their index the ventilation during the first minute of recovery after only one minute of exercise is used as an expression of exercise ventilation.

In our 228 subjects the indices showed a general relation to symptomatic "breathlessness." Fig. 6 is a scatter diagram relating the $D.I._2$ to the clinical grading of the patients into four approximate grades of breathlessness by Dr. C. M. Fletcher on the basis of the following standard questions:

Grade 1: Is patient's breath as good as that of other men of his own age and build at work, on walking, and on climbing hills or stairs?

Grade 2: Is patient able to walk with normal men of own age and build on the level but unable to keep up on hills or stairs?

Grade 3: Is patient unable to keep up with normal men on the level, but able to walk about a mile or more at his own speed?

Grade 4: Is patient unable to walk more than about 50 yards on the level without a rest?

Grade 5: Is patient breathless on talking or undressing, or unable to leave his house because of breathlessness? (Not used for test.)

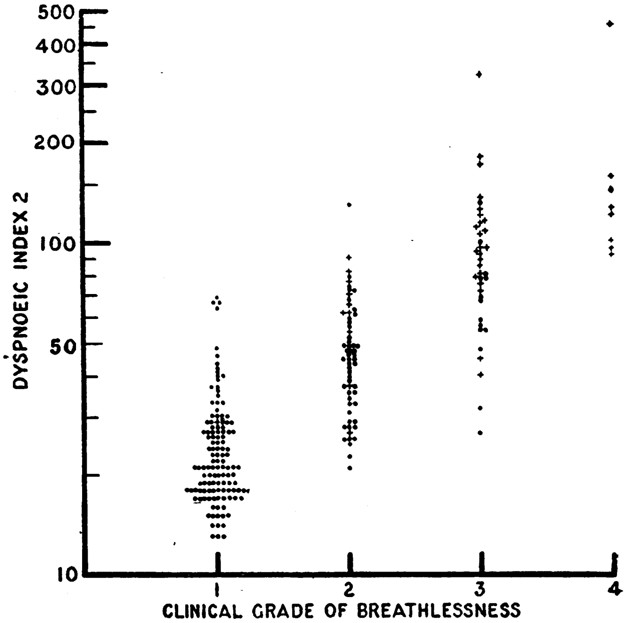

FIG. 6.—Scatter diagram relating the second dyspnoeic index ($D.I._2$) of 228 subjects to a grade of "breathlessness" as determined independently from clinical history.

There is a general agreement between the measured dyspnoeic index and patient's reply to the questions about his breathlessness.

The dyspnoeic index is plotted on a logarithmic scale for convenience. On a "straight" plot the relation between index and grade is non-linear, patients in the lowest clinical grades often having particularly large indices of dyspnoea. This effect may be due to the scale of grading, since scales of judgment are frequently non-linear. Moreover, on a straight plot there is a skewed distribution within each grade, especially in the first, which may have resulted from the dyspnoeic index having a limiting value of about 12% at the lower end, which represents the minimum ventilation at this level of exercise.

Normal Values.—Since the exercise results (the E.V. and the S.V.) are compared with the subject's M.V.V. to give an objective measure of breathlessness their "normality" *per se* does not arise. However, since one may wish to know whether a patient's exercise ventilation itself is excessive or not—for example, in the assessment or treatment of heart failure as is discussed below

TABLE IV.—*Average Value of the E.V. and S.V. Resulting from the Exercise Test, Together with the Corresponding Indices of Dyspnoea, in Four Different Age Groups of Normal Subjects and a Group of Athletes (Numbers in Parentheses Represent the Range of Values Found)*

Age	No. of Subjects	M.V.V.* (l./min.)	E.V. (l/m.)	$D.I._1$ $\left(\frac{E.V.}{M.V.V.} \times 100\right)$	S.V. (l./m.)	$D.I._2$ $\left(\frac{S.V.}{M.V.V.} \times 100\right)$
Athletes (O.U.A.C.) 23 years ..	17	187 (156–228)	30 (24–35)	16 (12–20)	27 (19–34)	15 (11–18)
Normal subjects 25 years ..	10	151 (125–178)	25 (19–33)	17 (11–26)	27 (22–33)	18 (13–27)
35 years ..	10	145 (75–176)	25 (19–36)	18 (13–25)	26 (20–37)	19 (14–29)
45 years ..	10	131 (102–149)	24 (20–30)	18 (13–27)	25 (22–30)	20 (14–23)
55 years ..	10	118 (83–157)	26 (22–31)	22 (16–28)	28 (21–38)	24 (18–30)

* Subsequent re-calibration of the M.U.V. apparatus shows these results may be slightly high. The error does not affect the conclusions.

—the values in 40 " normal " subjects, 10 in each of four age groups, is given as Table IV. The normal subjects were men most of whom were temporarily attending the Ministry of Labour's Employment Exchange in changing from one job to another. Only men with abnormal chest radiographs, hypertension, or clinical evidence of heart or renal disease were excluded. The results of testing 17 medium-distance runners of the Oxford University Athletic Team, whom we examined through the kindness of Dr. R. W. Parnell when he was investigating their physique (Parnell, 1951), are also included as the upper limit of " normality." It will be seen that the E.V. and S.V. are a very stable value not related to age, and decline in the dyspnoeic index, associated with the increasing breathlessness of ageing, is due to decrease in the ventilatory reserve as measured by the M.V.V.

Discussion and Conclusions

When this standard exercise test is to be used for measuring breathlessness it should ideally always be combined with some independent measurement of the patient's maximum ventilation such as the M.V.V., because breathlessness may arise either from a reduction in the maximum or from an increase in the exercise requirements, and only the latter can be measured by the test. In coal-workers' pneumoconiosis, for example, abnormal breathlessness on exertion, the cardinal symptom of the disease, is almost entirely due to reduction in the ventilatory capacity; excessive exercise ventilation does occur, however, mostly in men who have some evidence of right-sided heart failure (Gilson and Hugh-Jones, 1952), so that in this disease the exercise test is necessary to avoid error which would arise if the maximum voluntary ventilation alone were used for the objective assessment of breathlessness. In general cases of heart failure, on the other hand, abnormal E.V. is an important cause of breathlessness, and may be one of the earliest signs even when oxygen consumption is still normal (Harrison and Pilcher, 1930). In this case the measurement of the S.V. by the exercise test may itself provide a convenient objective method of assessment, though it should be supported by tests of maximum ventilatory capacity if occasional error is to be avoided.

One obvious effect, which might be thought to lead to error in the test, is hyperventilation through nervousness, mouthpiece resistance, etc. It certainly may cause an increased resting ventilation (R.V.) and then an apparently small exercise excess volume of air (E.E.V.). This means that the latter, which might otherwise be used as a measure of the test efficiency of the subject, may be erroneous. However, this reciprocal relation between the increased resting ventilation and the diminished volume of air caused by the exercise is such that their sum, the S.V., remains correct. Many cases of " nervous " hyperventilation occurred in the normal subjects among the 228 men examined and reported here, yet it was seen from Fig. 4 that their S.V. and E.V. agreed very closely.

In conclusion, the exercise test described in this paper has advantages in providing a known amount of work for the subject, comparable with a bicycle ergometer, but using only simple apparatus; a " submaximal " test which is not distressing for the patient or as time-consuming for the observer as testing maximal response; a valid quantitative result in the S.V., whether the patient completes the test or not provided two or three minutes of exercise is done. The S.V. is little disturbed by subjective influences, and its use means that repeated exercise tests are not required, as they are when the amount of work is varied to give a constant response.

Summary

A simple step-test is described which enables a patient to be given a known and standard amount of exercise, comparable to exercise on a bicycle ergometer, without the use of complex apparatus. The standard exercise is achieved by adjusting both the height and the rate of stepping to compensate for variations in weight between one patient and another, the appropriate values being got from a nomogram without calculation.

The exercise period is five minutes. A suitable work load is usually 350 kg.–m./minute.

The patient's ventilatory response is recorded with a domestic gas-meter. This is expressed as a " standardized ventilation " (S.V.), which is got from the ventilation in excess of the resting level during both exercise and recovery and gives a valid measure even if the patient cannot or will not complete the five minutes' exercise. In all subjects who complete the test the S.V. is numerically equal to the exercise ventilation (E.V.) at a steady state.

For measuring the symptom of breathlessness the ventilation caused by the exercise should be related to the patient's maximum voluntary ventilation (M.V.V.) measured independently. A dyspnoeic index $\left(\frac{\text{S.V.} \times 100}{\text{M.V.V.}}\right)$ is suggested as an alternative to the index previously used by other workers—namely, $\frac{\text{E.V.} \times 100}{\text{M.V.V.}}$. The former index avoids the necessity for repeat testing at a lower exercise level in those who fail to complete the exercise, when the usual index becomes invalid.

We wish to thank members of the Pneumoconiosis Research Unit, especially Dr. C. M. Fletcher (the director) and Dr. J. C. Gilson, for advice and many suggestions. We are indebted to Mr. P. D. Oldham, statistician to the unit, for his help in constructing the nomogram and designing the experiments.

REFERENCES

Baldwin, E. de F., Cournand, A., and Richards, D. W. (1948). *Medicine*, **27**, 243.
—— —— —— (1949a). Ibid., **28**, 1.
—— —— —— (1949b). Ibid., **28**, 201.
Behnke, A. R. (1942). *Milit. Surg.*, **90**, 9.
Belayew, D. (1948). *Arch. belges Méd. soc.*, **6**, 447.
Brittingham, H. H., and White, P. D. (1922). *J. Amer. med. Ass.*, **79**, 1901.
Comroe, J. H. (1950). In *Methods of Medical Research*, **2**, 95. Chicago.
Cotton, T. F., Rapport, D. L., and Lewis, T. (1916). *Heart*, **6**, 269
Garry, R. C., and Wishart, G. M. (1931). *J. Physiol.*, **72**, 425.
Gilson, J. C., and Hugh-Jones, P. (1948–9). *Clin. Sci.*, **7**, 185.
—— —— (1952). To be published.
Gray, J. S., Barnum, D. R., Matheson, H. W., and Spies, S. N. (1950). *J. clin. Invest.*, **29**, 677.
Hannon, J. W. G. (1945). *J. Indiana med. Ass.*, **38**, 391.
Harrison, T. R., and Pilcher, C. (1930). *J. clin. Invest.*, **8**, 291.
Hill, A. V., and Lupton, H. (1923). *Quart. J. Med.*, **16**, 135.
Hugh-Jones, P. (1947). *J. Physiol.*, **105**, 332.
Kaltreider, N. L., and McCann, W. S. (1937). *J. clin. Invest.*, **16**, 23.
Lundgren, N. P. V. (1949). *Proc. 9th int. Congr. on Indust. Med. London, 1948*, p. 274. Bristol.
Lupton, H (1923). *J. Physiol.*, **57**, 337.
Mann, H. (1918). *Arch. intern. Med.*, **21**, 682.
Master, A. M. (1935). *Amer. Heart J.*, **10**, 495.
—— and Oppenheimer, E. T. (1929). *Amer. J. med. Sci.*, **177**, 223.
Matheson, H. W., and Gray, J. S. (1950). *J. clin. Invest.*, **29**, 688.
Meakins, J., and Gunson, E. B. (1916). *Heart*, **6**, 285.
Nylin, G. (1933). *Acta med. scand.*, Suppl. 52.
—— (1936). Ibid., Suppl. 78.
Pachner, P. (1950). *Pracovní Lékarství*, **11**, 357.
Parnell, R. W. (1951). *British Medical Journal*, **1**, 1292.
Passmore, R., and Thomson, J. G. (1950). *Brit. J. soc. Med.*, **4**, 234.
Reisinger, J. A. (1938). *Amer. Heart J.*, **15**, 341.
Renner, W. F. (1951). *Arch. industr. Hyg. occup. Med.*, **3**, 129.
Wahlund, H. (1948). *Acta med. scand.*, Suppl. 215.
Warring, F. C. (1949). *Amer. Rev. Tuberc.*, **60**, 149.