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EXERCISE TESTS IN RELATION TO CARDIOVASCULAR FUNCTION

Report of a WHO Meeting

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WHO MEETING ON EXERCISE TESTS IN RELATION TO CARDIOVASCULAR FUNCTION

Geneva, 25-30 September 1967

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EXERCISE TESTS IN RELATION TO CARDIOVASCULAR FUNCTION

Report of a WHO Meeting

A WHO Meeting on Exercise Tests in Relation to Cardiovascular Function was held in Geneva on 25-30 September 1967. Dr S. Fox was elected Chairman, Dr K. Lange-Andersen Vice-Chairman, and Dr R. J. Shephard Rapporteur.

INTRODUCTION

Physical fitness, characterized by optimum responses to environmental stimuli, plays an important part in mental, physical, and social well-being, and may retard the aging process. Together with physical health, it is also important in equipping persons to fulfil specific tasks.

In contemporary society the pattern and intensity of physical activity are changing. In highly industrialized societies the necessity for hard physical work is diminishing; in developing societies, however, the changing patterns are less clear. An important aspect of such changes in physical activity is their possible relationship to health. Do changes in physical activity result in changes in fitness, and is there a concomitant alteration in the response to infection, toxic substances, heat, cold, and other environmental factors? Is the increased prevalence of heart disease in middle-aged men the result of decreased physical activity? If so, what may be done to remedy the situation?

Such questions are difficult to answer, owing to a lack of knowledge on (1) the relationship of man to his total environment; (2) habitual physical activity and its effect on fitness and on the incidence of heart disease; and (3) the relationship between physical training and the occurrence and prognosis of heart disease. There is, furthermore, no internationally accepted technique for the measurement of fitness in healthy and unhealthy subjects.

It was for the above reasons that WHO convened a meeting of experts to evaluate exercise tests and techniques for measuring habitual physical activity in both healthy subjects and subjects with heart disease. The primary objective of this group was to recommend reliable and internationally acceptable standard techniques for clinical and research use in evaluating physical fitness and habitual physical activity in normal subjects and those suffering from cardiac conditions.[1]

DEFINITION OF PHYSICAL FITNESS

Physical fitness is defined as the ability to perform muscular work satisfactorily under specified conditions, and may be assessed by:

(*a*) the magnitude, duration, and type of the maximum exercise that a subject can withstand;

(*b*) the relationship between the level of submaximum exercise and the response of the body to such exercise;

(*c*) the rapidity of recovery of the cardiorespiratory system from either maximum or submaximum exercise; and

(*d*) the degree of fatigue in prolonged activity.

Many aspects of fitness—e.g., aerobic power and anaerobic power and capacity—can be measured in physiological terms. Aerobic power is influenced by the different components of the oxygen transport system (lungs, cardiovascular system, haemoglobin mass, blood volume, skeletal musculature, and enzyme systems), but little is known of the factors that influence anaerobic power and capacity.

Brief periods of work, involving maximum efforts lasting less than 1 min, are largely dependent on anaerobic capacity and power. For moderate periods of work, in which the maximum effort lasts from 1 min to 1 hour, aerobic power is probably the main limiting factor. For prolonged work (i.e., high activity for more than 1 hour) aerobic power is less important, and muscle nutrition, local circulation, thermoregulation, and fluid balance play an increasingly dominant role. With all durations of activity, fitness measurements may also be influenced by motivation, skill, and environmental factors, and may be limited by clinical signs and symptoms.

For practical purposes, it may be possible to use the results obtained during work of moderate duration to estimate fitness for work of longer duration.

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[1] Information on different aspects of the relationship between cardiovascular health and physical fitness will be found in the following publications: (1) *Proceedings of the International Symposium on Physical Activity and Cardiovascular Health, Toronto, October, 1966*. In: *Canad. med. Ass. J.*, **96**, 695. (2) American Heart Association, Committee on Electrocardiography (1967) *Circulation*, **35**, 583. (3) Karvonen, M. & Keys, A., ed. (1967) *Proceedings of the Helsinki Conference on Physical Activity and the Heart*, Springfield, Ill., Thomas. (4) Report on the International Society of Cardiology Meeting, Makarska, Yugoslavia, September 1963, in: *Acta Cardiol. (Brux.)*, 1964, **19**, 305. (5) Cumming, G. R. (1968) *Circulation*, **37**, 4.

PHYSICAL FITNESS TESTS

Uses

Physical fitness tests are useful in many areas of medical practice and research. Although they do not in any way replace the necessity for clinical evaluation and judgement, they provide supplementary and indispensable information. Among their more frequent applications, they are used to assess the following factors:

(1) Fitness for work, sport, and other activities.

(2) The functional status of the cardiovascular and respiratory system in health and disease, including (*a*) the diagnosis of current status or the measurement of specific responses; and (*b*) prediction of the probability of the development of disease or prognosis of its future course if it is already present.

(3) Preventive, therapeutic, and rehabilitative regimens, including the effects of medication, surgery, physical training, and other potential means of improving health.

In addition, fitness tests have been used to reassure patients and motivate them to improve their health.

Although physical fitness tests provide useful information in all the above areas, their use has been limited mainly to research studies on healthy subjects and, in clinical practice, to the diagnosis and evaluation of coronary heart disease. Their clinical use has not been more widespread for the following reasons:

(1) Communication between physiologists and medical practitioners has been ineffective.

(2) A wide variety of different methods have been developed by physiologists, often without agreement on terminology, standard methods, and interpretation. In addition, there has been a serious lack of suitable equipment and of adequately-trained personnel.

(3) Clinicians have traditionally studied ECG responses to single-level or inadequately graded effort tests. These have been inadequate for a reliable assessment of physical fitness and results have been disappointing. Only recently have clinicians and epidemiologists begun to use the fitness tests established by physiologists to assess the condition of normal subjects and those suffering from cardiac malfunction.

Many of the tests used for clinical and epidemiological purposes are also applicable in research, since the basic design is similar. However, the techniques required for research purposes are likely to be more elaborate and complex. For example, for research purposes maximum aerobic power may be directly measured from maximum oxygen intake, but in clinical practice and in population studies it may be more practical to estimate physical fitness from measurement of the heart rate at standard submaximum work loads.

Limitations

Exercise tests measure physical fitness, but do not purport to take full account of all the emotional, motivational, environmental, and other factors that influence health, the course of disease, and performance in sports and other activities. Exercise tests do not measure the over-all lifetime reserves or the possibility of changes in fitness, nor do they predict the interaction of disease processes, emotional stresses, and environment.

A single test cannot determine whether a specific workload will be tolerated by a given subject in succeeding months and years. For this reason, periodic retesting is recommended.

Physical fitness tests are not specific; patients suffering from heart diseases of different etiologies give similar responses, as do those suffering from physical deterioration, lack of training, or anxiety and those under treatment with certain drugs. Despite this lack of specificity, however, there is a significant correlation between responses to physical fitness tests and cardiovascular mortality and morbidity. In groups who respond normally to electrocardiographically monitored exercise tests, morbidity and mortality rates are lower than in those who respond abnormally.

Prognosis of coronary heart disease

The prognostic significance of tests involving measurements of maximum oxygen intake has yet to be evaluated. In Scandinavia, in particular, many subjects were tested in this way five or more years ago, and the re-examination of such subjects should be encouraged and supported wherever practicable.

Tests involving electrocardiographic response to muscular exercise have some prognostic value. In particular, the development of segmental S-T depression by otherwise normal subjects during or immediately following heavy exercise is regarded as indicating a high risk of the development of clinical coronary heart disease. In subjects with arteriosclerotic heart disease, this change is considered to be indicative of earlier recurrence and increased mortality, other factors being equal. Prospective studies [1] in the United Kingdom and the USA have shown that men who develop this sign in response to approximately 3 min of single-level step-up exercise are 4-10 times more likely to develop clinical coronary heart disease within

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[1] Brody, A. J. (1959) *J. Amer. med. Ass.*, **171**, 1195; Mattingly, T. W. (1962) *Amer. J. Cardiol.*, **9**, 395; Rumball, C. A. & Acheson, E. C. (1963) *Brit. med. J.*, **1**, 423.

the next 3-10 years than are those who show no such ECG response. In some of these studies, exercise tests indicated as abnormal about half the persons who subsequently developed coronary heart disease (i.e., their sensitivity was about 0.5), but they also indicated as abnormal about 10 times as many subjects who did not develop such disease during the 3-10-year follow-up. Unfortunately, these findings cannot be extrapolated more generally because the groups studied were inadequately defined in terms of sampling, freedom from symptoms, length of follow-up, and other factors.

However, there seems to be sufficient evidence to encourage further studies of the predictive power of submaximum and maximum exercise tests, preferably with measurement of ECG response. Such studies should compare the sensitivity, specificity, feasibility, acceptability, and cost of different exercise tests and of other ways of measuring high risk factors. Since it is unlikely that any single test will completely separate those who will develop clinical coronary heart disease from those who will not, it is recommended that the predictive power of combinations of factors (environmental, psychological, genetic, physiological, anatomical, and pathological) be determined. A follow-up study of samples from communities differing in cultural and social background would also be of interest. So that such a study could be completed within a reasonable time, it should be designed so that data obtained from different sources could be compared and pooled.

TEST METHODS

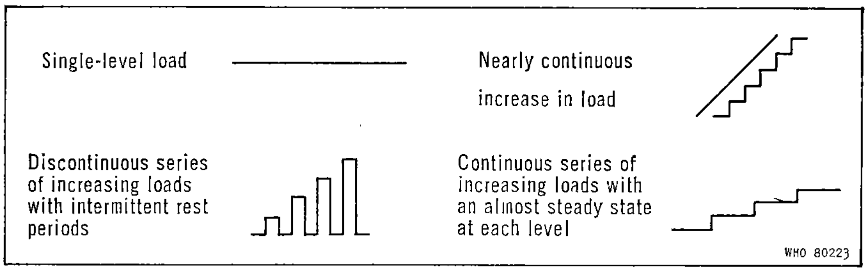
The primary objectives of cardiac exercise tests are evaluation of the stress effects of effort on the heart and circulation and definition of the limits of an individual's activity and of the factors that limit clinical management and prognosis. The tests should measure performance under standard conditions and should detect and assess symptoms and signs of cardiorespiratory distress that may preclude the attainment of maximum oxygen consumption.

It would be desirable to use similar methods for the testing of both healthy persons and those suffering from cardiac conditions. Ideally, the test procedures should be suitable for all ambulatory subjects, ranging from champion athletes to those with cardiac complaints. In practice, however, the type of test and the magnitude of the required effort should be selected with due consideration for the safety of the subject.

Types of exercise

The forms of exercise used in physical fitness tests are running, walking, pedalling an ergometer, stepping, and hand cranking. The different types

TYPES OF LOAD USED IN EXERCISE TESTS *



* Each of these types of load may be applied in any of the following types of exercise: steps or bench, upright bicycle, supine bicycle, and treadmill.

of load that may be used in such tests are illustrated in the accompanying figure, and publications on different test procedures are listed in the Annex. The accompanying table gives an evaluation of the relative merits of the three most widely used forms of apparatus (treadmill, step, and bicycle). It should be noted that the relative importance of the different factors listed in this table depends on the objectives of a test and the conditions under which it is performed. For this reason, the over-all merit of a given procedure cannot be assessed from the total " score " of its column in the table.

The order of preference of exercise tests is considered to be as follows: upright bicycle ergometer, step test, and treadmill. The test considered best suited to universal use is exercise on an upright bicycle ergometer, performed at several increasing workloads, each lasting at least 4 min, without intervening rest pauses (if such a test is well tolerated by the subject). When circumstances dictate the use of a step, comparison of findings is possible on the basis of the measured intensity of effort and the functional response.

If a test is used for measurement of maximum oxygen intake, the level measured should ideally be the greatest the subject can achieve. The relative levels of maximum oxygen intake vary slightly with the three types of exercise under consideration, and horizontal or uphill walking or running gives levels higher than stepping and bicycle pedalling; however, the differences are not so great that values obtained from the three types of exercise cannot be compared. Hand cranking has given substantially lower maximum oxygen-consumption values in several laboratories, but the use of some large types of crank has given values comparable with those obtained with pedalling. Since the hand crank is particularly useful for testing patients with impaired function of the lower limbs, it deserves further study.

If work rate rather than oxygen consumption is measured, efficiency should be constant at all rates of work and in all individuals. The tasks

RELATIVE MERIT OF EXERCISE TESTS *

Criterion	Type of test			
	Steps	Upright bicycle	Supine bicycle	Treadmill
A. EASE OF PERFORMANCE				
Familiarity with task required ?	+++	++	−	+++ [a]
Ease of obtaining high V_{O_2}	++	++	±	+++
Subject's performance to $(\dot{V}_{O_2})max$	+	++	+	+++
Ease of instrument calibration	[b]	++ [c], −− [d]	++ [c], −− [d]	+ or ± [e]
Ease of measuring applied power	++ [f]	+++	+++ [f]	[g]
Ease of recording or obtaining the following during maximum test:				
ECG	±	++	++	±
Blood pressure	−−	++	+++	−
Blood samples	−−−	++	+++	±
Respiratory volume and oxygen	±	++	++	+
Need for providing for emergency care [h]	+	−	+++	−−−
Ease of breathing	+++	++	+	+++
Ease of obtaining a nearly continuous increase of effort [h]	±	++ [c], +++ [d]	++ [c], +++ [d]	++ or ± [e]
B. FREEDOM FROM UNDESIRABLE FEATURES				
Hazards	+++ or ± [i]	+	+++	−−
Need for skill	±	+	−	++ [i]
Occurrence of local muscle fatigue at high exercise levels	±	−	−−	++
Need for trained personnel	++	++	++	±
Cost of equipment	+++	++ [c], −− [d]	+ [c], −− [d]	−−−
Ease of maintenance (including need for constant calibration)	+++	++ [c], ± [d]	++ [c], ± [d]	±
Freedom from noise	+++	±	±	−−
Bulk of equipment [h]	+++	+	−	−−−
Ease of transporting equipment [h]	+++	++ [c], ± [d]	± [c], −− [d]	−−−
Need for electricity [h]	[b]	++ [c], −− [d]	++ [c], −− [d]	−−−
Need for neuromuscular-skeletal co-ordination	−	−	+	−−
Ease of rate control [h]	−−	− [c], ++ [d]	− [c], ++ [d]	+++

* This table evaluates each of the four types of test according to the criteria listed in the first column. A grading of +++ indicates easiest, greatest freedom from undesirable features, most advantageous, etc.; a grading of −−− indicates most difficult, least freedom from undesirable features, least advantageous, etc. The intermediate point is represented by a grading of ±. Throughout the table, therefore, the greater the number of plus signs (or the fewer the number of minus signs), the fewer the problems presented by the test concerned.

[a] More difficult when the rate and slope are high. [b] Unnecessary. [c] Friction type. [d] Electric type. [e] Calibration easy for angle, less easy for rate. [f] Less easy at maximum power. [g] Can be estimated only. [h] Less important factor. [i] Less at low stepping rate, greater at high rate.

should be familiar and easy to perform, and the end-point should be general exhaustion and dyspnoea rather than local muscle fatigue. The tests should not provoke undue anxiety, nor should learning influence the maximum work rate attainable. Fortunately, the effects of learning on the treadmill, bicycle, and step tests are, for practical purposes, quite small.

The three-minute two-step (" double Master's ") test, a test of electrocardiographic response to exercise, is widely used for diagnostic purposes, but it has many limitations. For this reason, there is need of a multilevel exercise test that would assess the response of a subject at specified fractions of the total aerobic power of a normal subject of the same age. The pulse rate at 75% of the predicted " normal " $(\dot{V}_{O_2})_{max}$ for a given age and sex is considered to give the best approximation. Tables showing the corresponding pulse rates at different ages and suitable exercise loadings should be devised.

Procedures

Since the procedures involved in the different exercise tests have been fully described elsewhere,[1] this section will be limited to a few important observations on each test.

Stepping. It is important that both the rate of stepping and the height of the steps be standardized. The desired height is determined partly by rhythm and partly by work-load requirements. A rate of less than 60 paces (15 " round trips ") per minute may be uncomfortably slow, and a rate of more than 180 paces per minute leads to tripping. In order to attain the maximum work rate in fit young subjects, steps whose total height is at least 40-50 cm are required. The total number of paces taken by the subject and the actual time must be recorded in order to calculate the external work performed ; it is also vital to ensure that the subject stand erect on the top step after each ascent, and place both heels firmly on the ground after each descent.

Bicycle ergometer. Bicycle ergometers are constructed with either a mechanical or an electrical braking system. With both types of device frequent calibration is essential.[2] For most purposes a pedalling rate of 50-60 rev/min is optimum, but for high-performance tests the rate may be increased. A revolution counter should be used in calculating mechanical

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[1] Lange-Andersen, K. *Measurement of maximal oxygen uptake, and related respiratory and circulatory functions.* In : *IBP handbook* (in preparation) ; Denolin, H. & König, L. (1967) *Ergometry in Cardiology Symposium, Freiburg-im-Breisgau ; I. Internationales Seminar für Ergometrie, Berlin, 1965.*

[2] For further information, see : US Public Health Service (1967) *Calibration of two bicycle ergometers used by the health examination survey*, Washington, D.C. (US Public Health Service Publication No. 1000, Ser. 2, No. 21.)

work. A clearly visible speedometer, by which the subject can regulate his pedalling rate, is also helpful.

Walking and running. In the laboratory, walking and running can be studied on the treadmill. For field tests, a course that requires equivalent energy expenditure may be arranged.

The treadmill should be so designed that the speed and slope of the belt can be varied and measured. Safety precautions are more important with the treadmill than with the bicycle and step tests, particularly at higher speeds.

On a field course, the oxygen required at a given rate of walking or running is affected by the surface of the course and by the speed and direction of the wind. In uphill running, the oxygen requirement seems to be greater (since the body must be raised) than that of the same slope and distance on the treadmill.

Intensity, duration, and loading of tests

Intensity

Maximum aerobic work ($\dot{W}_{max}$) is the rate of work performed at the moment when maximum oxygen consumption is stabilized. Submaximum work comprises all rates below this level; hypermaximum work is any rate above $\dot{W}_{max}$, in which anaerobic metabolism is used to an increasing extent.

Maximum tests. It is widely held that if the objective is to determine $\dot{W}_{max}$, the maximum oxygen intake should be measured directly. Exercise of increasing severity is performed until no further increase of oxygen intake occurs; a satisfactory oxygen plateau is considered to be a nearly essential criterion of attainment of a true maximum. Good results can be obtained in well-motivated young adults, but the probability of obtaining true maxima is poorer if the subjects are less fit, randomly selected, and available for only brief periods of testing. The participants in the meeting believe that the presence of a physician is necessary during all maximum tests, even those carried out on normal subjects.

Submaximum tests. Almost all methods of assessing submaximum performance are based on the assumption that there is a relatively linear relationship between heart rate and either steady-state oxygen consumption or equivalent work rate, ranging from a certain minimum level of effort to $\dot{W}_{max}$. In order to determine this relationship, measurements should be made at several widely spaced levels of submaximum effort. The lowest such level should be at a pulse rate of more than 120 beats per minute (although this applies best only to younger subjects) and the highest should be as near the maximum as is consistent with safety and other appropriate considerations.

Maximum oxygen consumption (or maximum work rate) may be estimated from the results of submaximum tests in two ways.

(1) The results may be plotted in the form of a curve, which is extrapolated to a predicted maximum heart rate ; the corresponding oxygen consumption or work rate, which is assumed to correspond to $(\dot{V}_{O_2})_{max}$ or $\dot{W}_{max}$, is then read off. The predicted maximum heart rate must take the subject's age and sex into account.

(2) The pulse is measured at one or more submaximum loads, together with the corresponding oxygen consumption or work rate, and the maximum oxygen consumption is then estimated directly from a nomogram. The nomogram may be developed empirically or may be based on the linear relationship noted above. In either case, allowance must be made for the decline in maximum pulse rate with age.

The results of submaximum tests may also be reported directly, without estimation of the maximum oxygen intake. The usual procedure is to record either (1) the oxygen consumption or the work rate at a specified pulse level, or (2) the pulse rate at a specified oxygen consumption or work rate. As before, allowance must be made for the decline in maximum pulse rate with age. This can be done conveniently if all data are expressed so as to correspond to a constant fraction of aerobic power ; 75% is a convenient arbitrary level, being close to the onset of substantial anaerobic work.

The way in which the results of the test are reported depends on the purpose of the test and on the physical condition of the subject. However, the directly obtained data should always be reported.

Duration

In maximum tests, less time is required to obtain a satisfactory measurement at a given level than in submaximum tests ; however, the results should be rejected if a certain minimum duration of effort is not achieved. In submaximum tests, the time required to attain a relatively steady state varies with the pattern of loading ; for example, it may be somewhat less with multi-level than with single-level loads.

Loading

Three principal patterns of loading are in use as follows (see the figure on p. 10) :

Single-level load : Each individual performs exercise at a single constant level on a given day. The level is either kept the same for all subjects or it is changed according to the health and physical fitness of each subject.

This type of test can be used for measurement of the maximum oxygen intake and for " recovery " studies; after preliminary trials at differing levels it is also used for the study of the " maximum tolerated power " —i.e., the highest workload that can be tolerated for a specified time while a given factor such as ventilation is maintained at a constant level.

Discontinuous series of increasing loads : This type of test involves a series of exercises in which the load is increased in steps, between which short rest pauses are allowed.

Continuous series of increasing loads : In this type of test, the workload is increased in an almost continuous series of steps of variable short duration, without rest pauses; the truly continuous increase of workload is a special case of this procedure. An almost continuous increase of load can be achieved with a bicycle ergometer or a treadmill, but it is more difficult to achieve in step tests in which the work rate is increased by changes in the subject's pace.

The results of tests in which the load is continuously increased are closely comparable with those obtained by the repetition of constant-load tests on several days, this being true of both maximum and sub-maximum tests, and the former type of test is preferable for routine clinical purposes.

Preparation for testing

Testing should preferably be carried out in the morning, after a night with adequate rest. Exhausting muscular work should be avoided on the preceding day. An initial hour's rest in a comfortable environment without food or tobacco is desirable, as is a longer period without ingestion of stimulants, fatty foods, or a large meal. Drugs should preferably be withheld; if this is not possible, their levels and/or dosages should be recorded. Prior to testing the subject should be given a medical examination, including competent review of a multi-lead resting electrocardiogram. He should wear comfortable, light clothing, the test procedure should be explained to him, and he should be given a " warm-up " before the test proper. One of the aims of the preliminary explanation to the subject should be to allay his anxiety, since anxiety may increase the vulnerability of the heart to dysrhythmias.

The temperature of the room in which the test is conducted should be below 25°C and the relative humidity less than 65%. Excessive radiant heat must be avoided. If a fan is used, the effective temperature should be recorded. The altitude should also be recorded where appropriate.[1]

[1] For information on the effects of altitude, see : *The physiological effects of altitude : Proceedings of the Interlaken Symposium, September 1962,* London, Pergamon, 1964.

Contraindications and precautions

The use of exercise tests is contraindicated if the subject has any of the following conditions or symptoms:

(1) Manifest cardiac failure.

(2) Myocardial infarction or myocarditis within the past three months, or symptoms and ECG signs that show either of these conditions to be impending.

(3) Acute infectious disease, metabolic instability, or a probability of recent pulmonary embolism.

Suitable precautions must be taken when exercise tests are administered to persons who have any of the following conditions: atrial fibrillation or flutter, marked atrioventricular block, left bundle branch block syndrome, Wolff-Parkinson-White syndrome, and aortic stenosis.

During tests involving high work rates a physician should be nearby, irrespective of the health of the subject. The team responsible for testing must be able to recognize the signs and symptoms of impending difficulties and be competent to initiate appropriate therapy. Emergency equipment for cardiorespiratory resuscitation (including drugs and apparatus for defibrillation and for assisted pulmonary ventilation) should be kept in readiness. A cathode-ray oscilloscope is helpful in monitoring the electrocardiograms of subjects in whom there is increased risk of dysrhythmias.

After completion of a given workload or the entire procedure it is important to avoid postural hypotension and excessively rapid body cooling. A semi-reclining chair or bed may minimize postural problems; if the test is conducted in an upright posture, it may be necessary to taper-off the exercise gradually.

Indications for stopping exercise

The following symptoms and signs are usually considered to be indications that exercise should be stopped.

Symptoms: increasing pain, with or without ECG changes; fainting; severe dyspnoea; severe fatigue; and intermittent claudication.

Clinical signs: pallor; cold moist skin; cyanosis; staggering; confusion in response to enquiries; facies of cerebrovascular insufficiency; and head-nodding.

Physical signs: hypotension or lowered pulse pressure caused by exertion; and an increase in systolic blood pressure beyond prudent limits, depending on the age and clinical condition of the subject.

Electrocardiographic signs: paroxysmal superventricular or ventricular dysrhythmia; a succession of ventricular premature complexes occurring before the end of the T-wave ; conduction disturbances other than a slight a-v block ; and R-ST depression of horizontal or descending type greater than 0.2 mV.

Specific measurements

Detailed analysis of haemodynamics during exercise requires the measurement of cardiac output, heart rate, and pressures in the systemic and pulmonary circulations, together with a full study of the electrocardiogram. Such detailed studies can properly be performed only in highly specialized hospital laboratories. However, some useful circulatory measurements such as heart rate, brachial arterial pressure (by the indirect method), and simple electrocardiograms can readily be made in the physician's office and the field laboratory.

Heart rate

During moderate work, the heart rate may be counted with reasonable accuracy by palpation or auscultation. During heavy exercise, however, this becomes difficult and an ECG recording should be made.

Blood pressure

Accurate measurement of pressures in the systemic and pulmonary circulations can be made only by intravascular techniques, which are rarely practical in a field situation. The brachial arterial pressure can be measured indirectly during exercise, by means of standard clinical procedures. Systolic pressure is easily measured in this way, but the measurement of diastolic pressure is more difficult.

Electrocardiogram

In recording electrocardiograms, the same lead or leads should be used before, during, and after exercise. Records should be analysed for cardiac rhythms, atrioventricular and intraventricular conduction, and changes in the ST segment. The displacement and slope of the ST segment should be measured precisely. More information is obtained from a combination of leads representing the X, Y, and Z components of the ECG than from single-lead recordings. The exploring electrode is commonly placed on the chest in the C_4—C_6 positions with the reference electrode on the forehead or manubrium sterni or in the right C_6 position ; the " central terminal " may also be used. Other possible arrangements include unipolar or bipolar leads attached to the limbs.

Cardiac output

In hospitals, cardiac output is measured by techniques that require blood sampling and vascular catheterization (e.g., the direct Fick method or applications of the Hamilton principle), or precordial counting following intravenous administration of a radioactive isotope. However, such methods are not practicable in field situations.

Bloodless methods have been used for research purposes (the acetylene and carbon dioxide rebreathing procedures and the nitrogen monoxide procedure of Becklake), and it is recommended that development of these techniques for wider use should continue.

Oxygen intake

Open-circuit systems for the measurement of oxygen intake are most widely used for research purposes. The accuracy and widespread use of closed-circuit systems are limited by the following important defects:

(1) They are much more subject than open-circuit systems to errors arising from leakage.

(2) They can give erroneous results owing to displacement of the end-tidal position or alterations in thoracic blood volume.

(3) They are subject to volume errors arising from temperature changes, particularly at high metabolic loads.

(4) The performance of most available apparatus is inadequate in terms of resistance and inertia at high metabolic loads.

(5) The apparatus is bulky, clumsy, and expensive.

All determinations of respiratory gas exchange require careful and precise analytical work. To avoid systematic errors, it is advisable that measurement techniques be learned in a reference laboratory. In the reporting of results, all values should be referred to body weight.

Collection of expired gas. Care should be taken to ensure low resistance to breathing throughout the system, particularly in valves, stop-cocks, tubing, and bags or spirometers. Attention should be paid to the elimination of leaks, particularly at the mouthpiece; masks are less suitable than mouthpieces since they are more subject to problems with leaks, lifting of the seals, and dead space. Indoor experiments should be performed in well-ventilated rooms to ensure inhalation of fresh air.

Gas metering. A well-calibrated, reliable gas meter—e.g., a spirometer or a wet or dry gas meter—should be used for measuring the volume of expired air.

Gas sampling and analysis. An aliquot of the expired air should be accurately analysed for oxygen and carbon dioxide content by either chemical or physical methods. Chemical methods usually require less expensive apparatus and have slightly greater precision when used by well-trained personnel, but they are more time-consuming than physical methods.

Recovery measurements

Pulse. The form of the pulse recovery curve is rather disappointing as a measure of fitness, partly because it is difficult to apply an equal initial stress to patients who differ widely in age, fitness, and body weight. However, the recovery curve following standard exercise may be used to follow changes in the condition of a given individual.

Electrocardiogram. ECG anomalies may, in some instances, become more marked after exercise. The recovery ECG has diagnostic value (see page 17) and is of practical interest in that occasional extrasystoles during exercise should not be ignored, since they can progress to a more serious disrhythmia when the effort ceases.

Oxygen debt. The oxygen debt following exhaustive rhythmic exercise measures the capacity of the anaerobic system. It is of value in assessing fitness for competitive sports, but is difficult to measure and has little relevance to the fitness of the average person. The oxygen debt following submaximum exercise has some relation to cardiovascular function, but there is no clear evidence that it provides information that cannot be obtained by measurement of maximum oxygen intake.

Other physiological measurements

For certain specific applications additional measurements may be made, such as respiratory factors (static and dynamic lung volumes and diffusing capacity); circulatory factors (heart volume, blood volume, and total haemoglobin); blood lactic acid; arterial pO_2 and pCO_2; blood pH; and various aspects of muscle function such as maximum isometric strength.

Anthropological measurements

The minimum requirement in physical fitness testing is the measurement of height and weight. Measurements of skinfold thickness are also desirable.

Other stress tests

Hypoxia has sometimes been used in the evaluation of coronary heart disease; however, there is no evidence that it conveys more useful information than is obtained from exercise tests. Other procedures involving the use of thermal stress, cardiac pacing, or drugs are of interest and warrant further research.

Nonspecific "fitness tests"

A wide variety of nonspecific "fitness tests" have been developed, mainly by schools of physical education; many are based on the measurement of gymnastic performance. However, with the exception of the time required to run 800 or 1500 m (not commonly included in such tests), their correlation with cardiovascular health is so disappointing that they are not considered in this report.

A second group of nonspecific tests is based upon the analysis, in different ways, of heart rate and pulse pressure. To the extent that there is a limited association between pulse pressure and stroke volume, such tests have some theoretical justification; however, the participants in the meeting felt that there is little merit in making more than a simple statement of what the heart rate or the pulse pressure are under specified conditions.

INTERPRETATION OF RESULTS

The results of physical fitness tests may be interpreted on the basis of the following criteria: (1) the measured performance of external work; (2) the maximum oxygen intake; (3) the adaptation of the cardiovascular and respiratory systems; and (4) the electrical reaction or response of the heart (ECG).

The fitness of subjects whose maximum oxygen intake can be measured, or closely estimated, can be classified on this basis. Such subjects can then be compared and changes in their fitness status can be followed. Similarly, mean values for populations can be compared, while the relative fitness of individuals can be classified according to precise and definable criteria such as $(\dot{V}_{O_2})_{max}$ and $(\dot{V}_{O_2})_{max}$ per kg body weight per min. Fitness thus assessed can be considered a reasonable expression of health status. However, it does not preclude the presence of organic disease, any more than lack of fitness necessarily implies its presence.

If there are contraindications, it may be unsafe or at least unwise to expose subjects to tests of maximum oxygen intake or even to exercise levels at which they develop symptoms or signs of pathophysiological strain. In such subjects, evaluations of fitness based on responses to submaximum workloads may be highly informative, and are an important basis of comparison provided that comparable workloads are used.

The maximum oxygen intake of some subjects cannot be measured or even roughly estimated by extrapolation. The tests can then be interpreted by the magnitude and nature of the limiting factors at the highest oxygen intake an individual can attain. Both the limiting factors (e.g., the appearance of bundle branch block, marked ST segment displacement, or disproportionate rise of systolic blood pressure during exercise) and the workload at which they appear can be measured and compared. Tests that are terminated for clinical reasons can be interpreted as indicating that a subject is not only unfit but has an increased likelihood of the presence of either organic disease or of its precursors. If such results are obtained, they should lead physicians to institute corrective measures.

Limiting factors that are subjective, such as pain or faintness, and that are not accompanied by objective signs of dysfunction, may be related to quantifiable factors or may be an indication of disease. For example, claudication of a limb may later be shown by arteriogram to be the result of local arteriosclerosis.

Changes in the electrocardiogram should be considered in relation to the workload and to changes in other measurements of cardiovascular function, particularly heart rate and systemic blood pressure. A crude index of myocardial oxygen needs may be expressed by the product of the heart rate and the systolic blood pressure; for more precise measurements, heart dimensions must be taken into account. A deficient myocardial oxygen supply can be caused not only by a deficient coronary blood flow but also by disproportionate oxygen requirements of the heart. Thus, similar changes in ST contour may be found in patients with coronary artery disease and in those with valvular disease but normal coronary arteries. Other causes of altered myocardial metabolism that can cause apparently pathological changes of ST contour include increased sympathetic activity, anxiety, neurocirculatory asthenia, hyperthyroidism, anaemia, infections, and the use of drugs that affect the myocardium. Some estimate of the oxygen deficiency of the myocardium may be obtained by measuring the changes in the ST segment, at least in patients affected by coronary disturbances. The ST changes should be considered in relation to the workload upon the body and the heart; thus, the myocardial oxygen deficiency is greater in subjects who develop ST changes at lower relative work levels, and the prognosis is probably correspondingly less good. Although such changes are not diagnostically specific, an inference of coronary artery disease is strong once the above factors are excluded and other conditions are considered unlikely. On the other hand, the absence of ECG changes does not exclude the presence of significant coronary disease.

CORRELATION OF FITNESS TESTS WITH OTHER ACTIVITIES

The response to exercise tests provides information about aerobic power that may be valuable in the counselling of persons for work and other activities. Although exercise tests do not evaluate a subject's response to emotional and environmental factors that can influence performance, they provide an objective measurement of physical fitness under test conditions.

Furthermore, they make it possible to compare a subject's measured or estimated aerobic power with the peak and average energy demands of specific activities.

It is possible to assess the energy demands of a given job from a detailed description of the job—i.e., the type, speed, and pattern of work; the environment in which it is performed; the skills required; any bending, lifting, and stooping that is involved; and the transport necessary to and from work and on the job. The results of some such studies of the energy levels of jobs and recreational activities have been published.[1]

To determine the suitability of a job from the standpoint of energy, both the peak and the average caloric requirements should be compared with the subject's fitness. The duration and magnitude of peak efforts should be estimated, and compared with the peak levels of the exercise test that the subject tolerated without symptoms or signs of " strain ".

It is usually the capacity for peak rather than for sustained effort that is the limiting factor in determining the suitability of a job. Dock workers, steel-mill workers, and farmers reach high levels of energy expenditure in spurts of about 2 minutes' duration, each of which is followed by a similar period of rest. If the peak effort required for a job exceeds a person's maximum aerobic power, the job should be modified, either by a change of pace or by elimination of those aspects that require excessive effort. If this is not possible, the job should usually be considered inappropriate for the person concerned.

The maximum aerobic power is also an important determinant of the level of sustained work that is suitable for a given person. The allowable mean caloric expenditure of normal subjects is considered to be approximately 35-50% of their maximum aerobic power; for subjects with heart disease the percentage should be adjusted individually. For example, if a 75-kg subject has a maximum aerobic power of 2.25 litres of oxygen per minute (30 ml/kg/min), an average sustained workload of 1.1 litres per minute (15 ml/kg/min) or 5.5 kcal/min would be allowable. Whether a person's job is within his capacity can then be estimated from published data on the energy requirements of his work. Ergometric studies have shown that the energy requirements of most sedentary and of many factory jobs in highly industrialized countries are low, averaging 2.5 cal/min. The highest workload is often imposed by walking or stair climbing. Further research in this area is necessary.

In view of the complicating effects of emotional stresses and the environment on physical performance, it is important to determine whether the subject has been properly placed and has made a satisfactory adjustment

[1] Durnin, J. V. G. & Passmore, R. (1967) *Energy, work and leisure*, London, Heinemann; Spitzer, H. & Hettinger, T. (1966) *Tables donnant la dépense énergétique en calories pour travail physique. Cahiers du B.T.E.*, Paris.

to his total environment. To some extent, this can be done by means of objective physiological measurements and by study of the subject's work record (productivity, safety and absenteeism), the symptoms and signs (particularly fatigue) he shows during and after work, and his emotional adjustment.

Physiological measurements at a practical clinical level, such as the pulse rate during 15-30 seconds of each minute following certain activities, can be simple and informative. Cumulative fatigue is indicated by a lengthening of the recovery period, a rise in the resting pulse rate, and a higher pulse rate (following a given effort in the same environment) after working hours than during the working day. The blood pressure and respiratory rate are also simple and useful criteria. Criteria of a disproportionate response to work include a resting pulse rate above 100/min, with a prolonged pulse recovery period ; a peak pulse rate above 130/min during moderate work involving the expenditure of 4-6 kcal/min ; a disproportionate increase in diastolic pressure ; increasing fatigue persisting through non-working hours ; and increasing cardiac symptoms at work and at home.

Periodic retesting is recommended because a single determination of maximum aerobic power does not predict the clinical course of health or of heart disease if present, nor does it indicate whether a specific workload can be tolerated by a given individual for months or years.

The requirements of both work and leisure activities should be evaluated in order to make realistic recommendations. With the development of industrial mechanization and automation the physical requirements of work are constantly decreasing, greater emphasis being placed upon intellectual competence and skills of lower energy demand. As such changes continue, the caloric requirements of many jobs will decrease, and other aspects of performance (particularly psychological aspects) will assume greater importance than maximum aerobic power.

USE OF FITNESS TESTS IN REHABILITATION

Since the physiological impact of heart disease can vary so widely, the physician should continually evaluate the functional capacity of cardiac patients throughout the periods of acute illness, convalescence, and rehabilitation.

During acute illness and convalescence, the physician clinically appraises the changing fitness of the patient according to his tolerance to greater effort. Both the caloric cost of specific activities and the corresponding physiological responses can be measured. Physical signs and electrocardiograms can be recorded before, during, and after progressively increased daily activities. Such activities should be carefully prescribed and supervised.

During convalescence and recovery, it is often difficult to evaluate cardiac function from clinical impressions, particularly in subjects who do not show cardiac enlargement or heart failure. Clinical signs and symptoms may be obscured by the patients' psychological responses, their level of motivation for work, the social pressures that affect them, and variations in their pain thresholds. Objective measurement is thus often necessary in order to evaluate cardiac function and assess the effects of therapy. Observations should include not only the electrocardiogram, but also the heart rate, systemic blood pressure, and possibly cardiac output with calculation of the tension-time index.

Serial submaximum exercise tests provide an objective basis for regulating the rate of rehabilitation and determining the appropriate time for a return to work. Such tests are particularly valuable in assessing the relative merits of different physical conditioning programmes for normal subjects and for subjects prone to heart disease, as well as of reconditioning and secondary preventive programmes for subjects already stricken with various forms of heart disease.

HABITUAL PHYSICAL ACTIVITY

One factor that may cause increased incidence and prevalence of coronary heart disease in man is a change in his habitual physical activity, which may be defined as the physical workload to which a person is usually subjected during his work and leisure. Both the total load and the pattern of such activity are of interest to the investigator.

The above definition ignores environmental stimuli such as heat and cold and other factors such as emotion, responses to which are superimposed on those produced by the workload. Furthermore, the responses of the body are modified by experience and by physical condition. It is easier to measure the responses than the stimuli, but the complexity of the stimuli should be carefully considered in assessing the responses.

Habitual physical activity varies from one individual to another (and with sex and age), from day to day, and from season to season.

Methods of measurement

Methods used in the past have required both the close co-operation of the subject and great technical skill on the part of the investigator. For this reason, few experiments have been conducted, and there is at present no clear understanding of the effects of habitual activity. This section reviews methods of assessing habitual physical activity and points out those that appear to be most promising.

If worthwhile measurements of habitual physical activity are to be made on large groups, certain aspects of technique must be given the closest attention. The methods used should be applicable to all walks of life, to all ages, and to both sexes. Ideally, they should be accurate and give reproducible results, although some loss of accuracy may be permissible in the study of large populations. The total cost of such methods should be low enough to permit both extensive and intensive studies, and the apparatus required should be simple to operate, rendering it unnecessary to employ highly-trained operators.

Direct measurement

Direct measurement of habitual physical activity is at present difficult, time-consuming, and arduous; furthermore, it is doubtful whether it is the most useful procedure in relation to the objectives listed above.

The following methods have been used for making direct measurements:

(1) The timing of activities by observers.

(2) The timing and recording of activities by the subjects (the diary technique).

(3) The recall of activity after the event, either directly by the subject (through questionnaires) or by means of interviews.

(4) Accelerometry and pedometry.

(5) Ciné or time-lapse photography.

The techniques listed above can give little more than a rough indication of habitual activity unless large numbers of investigators are available. However, simplified versions of the diary and recall techniques can be used to define groups involved in heavy, moderate, and sedentary work.

Indirect measurement

In general, indirect procedures measure the response of the body to all stimuli (physical activity, mental activity, and environmental factors such as temperature and noise). However, certain responses reflect physical activity more precisely than others. Measurements of energy consumption (e.g., dietary intake and oxygen consumption) are less influenced by "extraneous" stimuli (i.e., mental activity and environmental factors) than are measurements of cardiovascular, respiratory, or temperature-regulation responses. However, they suffer from other shortcomings; for example, a considerable time elapses before changes in activity are accurately reflected by changes in food intake, and dietetic studies are unlikely to give a true indication of the level of activity unless they extend over at least 5 days.

Although oxygen consumption does not reflect rapid changes in activity, it may be regarded as an absolute yardstick for the measurement of activity of such duration that it is likely to influence cardiorespiratory health.

Long-term measurement of oxygen consumption poses serious problems of comfort and acceptability, and its use for population studies would require large teams of skilled investigators; it is, therefore, applicable only to small groups and to relatively short periods of observation.

To assess the habitual activity of large and randomly selected groups of people, it is necessary to measure responses of the body to work that are more indirect than oxygen consumption. Such responses include the following:

(1) Cardiovascular responses: heart rate, blood pressure, and ECG changes.

(2) Respiratory responses: ventilation volume per minute and ventilation rate.

(3) Temperature-regulation responses: body temperature and sweat rate.

(4) Metabolic responses: blood and urine levels of metabolites and their breakdown products and the ionic concentration of body fluids.

None of the responses listed above is uniquely or linearly related to the stimulus of physical work. Furthermore, many of them are of only theoretical interest at present.

In selecting a response to be measured and a method for measuring it, the following factors must be taken into account: (1) the nature of the information required, the form in which it is required, and the degree of precision that is desired; (2) the practical problems of large-scale surveys; and (3) the acceptability of the method to the subjects.

The information required may include not only habitual physical activity but also the response of a certain body system to work. The degree of precision that is necessary depends on the purpose, design, and scope of the study and should be clearly defined in the planning stage.

Data should yield the greatest possible amount of information with a minimum of processing. Furthermore, they should not be more detailed than necessary; for example, whereas it may be important to have a beat-by-beat analysis of heart rate for certain studies, mean heart rates or specific frequency distributions may be sufficient for others.

The reliability of the measuring system becomes increasingly important as the extent of a survey is increased. In population studies, the acceptability of the method is also important; a method that is only slightly unpleasant may significantly affect the activity of the subjects, or may lead to the selection of a biased sample.

There can be little doubt that the measurement of heart rate is at present the most useful way to assess habitual physical activity. However, use of the heart rate as a measure of aerobic metabolism is subject to the same limitations in the assessment of habitual physical activity as in the assessment of physical fitness. The following techniques have been used for the measurement of heart rate :

(1) Photoelectric measurement.

(2) Continuous recording of the electrocardiogram, either by telemetry to a distant recorder or by a tape recorder carried on the person.

(3) Electrochemical integration.

Photoelectric measurement has proved useful, but the equipment required is obtrusive and the results are subject to numerous external sources of error. Telemetry is technically complicated and is unsuitable for large-scale use on free-living populations. Available tape-recording systems are rather expensive and cumbersome, and their timing is not completely reliable. However, they have the advantage of making it possible to obtain minute-by-minute or beat-by-beat analyses and to analyse ECG changes after a period of activity. Electrochemical integrators give only mean heart rates or, in their more advanced form, specific frequency distributions, but have the advantages of being much smaller, less obtrusive, and cheaper and easier to maintain than the other systems.

In population studies that use heart rate as the index of habitual physical activity, other " extraneous " stimuli (particularly heat, humidity, noise, and vibration) must be assessed or measured, ideally by body-borne instruments that do not inconvenience the subject. Unfortunately, instruments for assessing emotional and psychological factors are not available, although the electrochemical integration technique is undergoing development for this purpose. Portable multichannel tape recorders are also in the developmental stage.

RECOMMENDATIONS

Attention is drawn to the necessity for stimulating the following activities :

(1) Research aimed at developing improved exercise tests, which are considered to be among the most promising ways to detect and prevent cardiovascular disease, improve its management, and rehabilitate persons already suffering from it. In particular, standard procedures for physical fitness tests should be developed and should be applied to studies of (*a*) the relative incidence of ischaemic heart disease in subjects of varying physical

fitness and in those of differing levels of habitual physical activity, and (*b*) the effect of increased physical activity and training on prognosis. The problem of standardization of methods should be reassessed periodically.

(2) Investigation of the applicability of different tests to large populations, of their acceptability and cost, and of the comparability of data that can be obtained from their use.

(3) Development of improved techniques for the determination of habitual physical activity. There is urgent need for intensive research on promising methods, such as the measurement of heart rate and other cardiovascular functions during work and leisure. International co-operation is needed for both the development of techniques and their use to test persons in different environmental conditions.

(4) Development, evaluation, and more widespread co-operative use of efficient techniques of data acquisition, handling, analysis, and interpretation.

(5) Broad ecological studies of man and his environment.

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Annex

PUBLICATIONS ON DIFFERENT TYPES OF EXERCISE-TEST PROCEDURE *

Pattern of load *a*	Steps or bench	Upright bicycle	Supine bicycle	Treadmill
Single-level load	8, 16, 17	27	11, 27	9, 19, 22
Nearly continuous increase in load	21	6		5, 12
Discontinuous series of increasing loads with intermittent rest periods	20, 29	1, 2, 13, 15, 29	14	4, 6, 18, 25, 26, 29
Continuous series of increasing loads with a nearly steady state at each level		3, 10, 23	28	7, 29

* The numbers in the table refer to the references below.

a For further explanation of the pattern of loading, see the figure on p. 10.

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