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OPTIMUM PHYSICAL PERFORMANCE CAPACITY IN ADULTS

Report of a WHO Scientific Group

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OPTIMUM PHYSICAL PERFORMANCE CAPACITY IN ADULTS

Report of a WHO Scientific Group

INTRODUCTION

A WHO Scientific Group on Optimum Physical Capacity in Adults met in Geneva from 22 to 28 October 1968. Dr J. Karefa-Smart, Assistant Director-General, opened the meeting on behalf of the Director-General.

Until recently health was improving throughout the world, and there are good reasons to believe that this tendency will continue in developing countries. Unfortunately, however, there are definite indications that this no longer holds true for the middle-aged male population in some European countries. Increasing mortality rates are associated with a higher incidence of cardiovascular diseases and also with a lower level of physical fitness.

Many attempts have been made to explain the reasons for this deterioration in the general state of health of these population groups, and one of the hypotheses is that decreasing daily physical activity contributes to its occurrence. It is this aspect that is dealt with in this report, although it is recognized that many other factors play a role.

The interrelationship between health and physical activity has been studied by many investigators, and it has become evident that hypokinesia leads to a deterioration in musculoskeletal and cardiopulmonary function. There are also indications that physical inactivity increases the risk of ischaemic heart disease. It has, however, proved very difficult to relate the effects of physical activity to health in general.

To describe the health effects of variations in physical activity, the concept of physical performance capacity (PPC) is necessary. The PPC of an individual comprises different elements, which may be listed as follows :

1. Subjective exercise tolerance.
2. Maximum aerobic power — $(\dot{V}_{O_2})$ max — and endurance.

Maximum aerobic endurance is usually defined as the maximum time a certain fraction of the maximum aerobic power can be sustained.

3. Maximum anaerobic power and capacity.
4. Maximum muscular strength and endurance.
5. Neuromuscular co-ordination.

Methods for measurement of these elements have been developed, especially for maximum aerobic power and for maximum muscular strength and endurance. Only these two variables will be dealt with in detail.

Although the amount of comparable data on the PPC of populations in different parts of the world is very limited, there are indications that there is a marked decrease in the PPC of population groups in developed countries. This raises the questions whether these groups would be better off if their PPC were higher, if so, what level would be desirable and, finally, how it could be achieved. The Group came to the conclusion that at this stage no recommendations can be made for an optimum level of PPC but that standard values could be derived from population groups that seem not to have been affected as yet by the decrease in developed countries.

The Group was unanimous in its opinion that health would be promoted by the amelioration of any abnormally low PPC and therefore gave much attention to the possibility of training for the different components of the PPC. This is the more desirable because it was doubted whether man's usual daily physical activity, both occupational and leisure, even if relatively high, can guarantee a sufficiently high PPC.

Further research seems to be necessary to establish the intensity, frequency, duration, and type of physical activity required to achieve and maintain the PPC required for an optimal state of health.

In the young, activities leading to a balanced development of speed, strength, endurance, and skill appear to be desirable. In adults, the aim of physical activity should be to conserve or increase the abilities acquired. In old age, physical activity is needed for the conservation of motor and functional capacity and for the prolongation of the active and productive period of life.

HEALTH IN RELATION TO PHYSICAL ACTIVITY

Physical activity is related to all the three aspects of health; physical, mental, and social. The potential impact of physical activity on mental and on social health is recognized and there is need for active research in these fields. However, detailed discussion of these relationships was outside the terms of reference of the Group.

For the evaluation of physical health, mortality and morbidity are the most commonly used criteria. The possibility of using other criteria for the measurement of levels of health has been discussed by a WHO Study Group (1).

As an outcome of research over the last few years on the epidemiology of chronic disease, the concept of risk factors has also become established as a useful criterion for physical health. Risk factors are observable or measurable characteristics of the clinically healthy subject which make it possible to predict the incidence or the prognosis of disease, injury, or handicap.

Risk factors can be expressed in quantitative terms relevant to the type of population from which they are derived. It would be possible to use the term « health factor » to express the opposite of a risk factor, i.e., a characteristic associated with a lower than average incidence of disease, injury, or handicap.

Lack of physical activity — hypokinesia

Lack of physical activity induces changes in cell metabolism and in the musculoskeletal, cardiovascular, and nervous systems.

Inactivity induces changes in cell metabolism, manifested for instance in the alteration of enzyme activity.

In the musculoskeletal system the changes consist of decalcification of bone, substitution of muscle tissue by connective tissue and fat, and nitrogen loss.

The changes in the cardiovascular system include tachycardia at rest and during exercise in the supine and upright positions, ECG alterations, changes in the contractile properties of the myocardium, and lability of cardiovascular regulation.

In the nervous system changes in autonomous regulation occur and sometimes also psychoneurotic manifestations.

Physical training

Regular and adequate physical training increase both the morphological and functional capacities of the human organism.

Morphological adaptation can be observed by changes in body shape, in the skeletal and muscular systems, and in the lungs, heart, and other organs.

Functional adaptation manifests itself in, for instance, the relationship between maximum aerobic power and anthropometric and haemodynamic variables (page 21).

Damaging influence of inappropriate physical activity

Physical activity may be too great in intensity or duration, asymmetrical, or performed in an unnatural position or an adverse environment.

Such activity may cause overstrain of a part or the whole of the organism and induce local or general damage. One of the aims of occupational and physical medicine is to discover the causes of overstrain or damage and to prevent and treat it. Regulated physical activity is one of the preventive and therapeutic measures employed for this purpose.

Physical activity in prevention and treatment of disease

Physical exercises have an established place in the treatment of several diseases and disorders and play a major role in medical and occupational rehabilitation.

In recent years occupational physical activity has decreased in many parts of the world. Parallel with this, the spectrum of diseases has altered markedly, which has stimulated studies on the prophylactic and remedial value of physical activity.

Ischaemic heart disease. Interest in physical activity as a positive health factor has, during recent years, concentrated largely on ischaemic heart disease. Epidemiological studies on occupational differences in mortality and morbidity have indicated that in some populations men in physically active occupations experience less ischaemic heart disease than those in sedentary work (2, 3, 4). In other populations, however, such a difference apparently does not exist (5). The observed differences in morbidity of different occupational groups may also not be conclusive because they cannot be ascribed solely to physical activity, since both choice of occupations and different socio-economic conditions may influence the characteristics of occupational groups in many ways.

Epidemiological studies on former athletes are fewer than on occupational groups and have generally been performed on smaller groups. The longevity of athletes has been shown to be either practically the same as or higher than that of the general population. However, athletes obviously are often a socio-economically favoured group, hence the general population may not be suitable for comparative purposes. Participation in university sports does not cause much difference in longevity between students (6, 7, 8).

Several favourable characteristics have been observed in former endurance athletes even at an advanced age : a lower blood pressure, a larger heart volume, a greater aerobic power, and less intense smoking habits than in matched controls (9).

In longitudinal studies of ischaemic heart disease, some indices of habitual physical activity and physical performance capacity have emerged as significant predictors of ischaemic heart disease mortality. During a 12-year follow-up in the Framingham study (10), active life habits, a strong hand grip, a high vital capacity, and a low resting heart rate were associated with a lower than average mortality.

In another longitudinal study in the USA, leisure-time physical activity was associated with a lower risk of ischaemic heart disease, while the physical activity of occupation had no effect (11).

While in many investigations an elevated serum cholesterol, a high blood pressure, and cigarette smoking have emerged as significant factors in ischaemic heart disease, the results concerning the role of physical activity and obesity have been less consistent.

The possibility of preventing ischaemic heart disease through physical activity in periods of leisure would have obvious public health implications and deserves thorough study. The feasibility of launching a large-scale " intervention " study, in which middle-aged men would be induced to engage in regular leisure-time activity, is being studied at present in Finland and in the USA. While in the latter country poor co-operation on the part of the subjects has tended to discourage the initiation of the study for primary prevention, Finnish experience has so far been considerably more favourable. However, most people who have recovered from myocardial infarction are much more strongly motivated to participate in prescribed exercises, therefore studies of secondary prevention by exercise should be easier to carry through.

Groups with exceptionally restricted physical activity may also contribute to the study of the relation of physical activity to ischaemic heart disease. Examples are blind persons and subjects with certain handicaps of the locomotor system.

Peripheral arterial disease. In the medical treatment of peripheral arterial disease exercise has proved to be a potent therapeutic agent, effectively increasing the distance walked without pain (12). This justifies the conclusion that exercise may also play a role in the prevention of peripheral arterial disease, perhaps by stimulating the growth of collaterals. An effect on the disease process itself may not be necessary to achieve clinical improvement.

Blood pressure. Brief physical exertion causes a transitory increase in the systolic blood pressure in normal subjects, but does not influence the diastolic pressure to any major extent. In prolonged exertion the systolic pressure increases initially but may then decrease with time (13).

In patients with hypertensive disease at stages I and II (14), brief exertion diminishes the systolic and diastolic blood pressure for a short period after work, sometimes considerably (15).

In patients with orthostatic hypotension, physical training has been found to normalize the blood pressure when the patients are in an upright position.

In some longitudinal studies of endurance training, a hypotensive effect has been observed on the systolic and diastolic blood pressure (16).

This phenomenon was also found in some studies of active and of old sportsmen (9, 17).

Vasomotor regulation. The influence of physical training on vasomotor regulation can be illustrated by the results obtained in patients with vasoregulatory asthenia (VA) (18), which is a regulatory vasomotor disturbance characterized by psychasthenia, a low PPC, and a high orthostatic heart rate, both the latter findings being caused by a hyperkinetic circulation, the oxygen inspired being transported with a larger than normal cardiac output. The VA disturbance is also accompanied by typical ECG changes (depression of the ST-T segment and a positive after-potential). The heart function is normal. The VA syndrome can be completely abolished by administration of β blocking agents. Patients with VA have been treated successfully with the aid of physical training involving large muscle groups (19).

Locomotor system. Many complaints about ill health, pains, and malfunction of diverse organs may be related to a subnormally functioning muscular system. There seems to be enough evidence to substantiate the assumption that weak muscles often cause the more passive structures of the body — e.g., the joints, the ligaments, the connective tissue — to be overloaded and thus strained. The reflexes that normally protect these structures presuppose a musculature strong enough to be effective.

The nutrition of bone and cartilage is highly dependent on the mechanical stresses and strains that these structures undergo. The flow of lymph and intercellular fluids is stimulated by the intermittent loading and relaxing of the cartilaginous tissues in joints and intervertebral discs, and the pulls of the muscles are the main source for the necessary changes in pressure. Physical activity has both an immediate and a long-term effect on the cartilage and is therefore of importance for these passive structures (20). The correlation between certain disorders of joints and bones and untrained musculature is not fully elucidated, but a striking effect in many such disorders has often been observed with supervised muscle training.

For the proper function of the peripheral vascular system, a well-developed musculature also seems to be necessary. The return of the venous blood, especially from those points of the body that lie below the level of the heart, i.e., from the lower extremities in the upright position, is to a high degree influence by the pumping action of the muscles in the legs. Muscle training has definitely a good effect on the orthostatic syndrome (20).

The role of the musculature in protecting the internal organs, especially in the lower abdomen, is undoubtedly very significant. Investigations, however, are needed on the relation of the strength of the abdominal muscles to diseases of the internal organs. The beneficial effect of training of the abdominal and pelvic muscles on the well-being of pregnant women must also be mentioned.

Many painful conditions in the muscles themselves are caused by their incorrect use; unnecessary muscle tension in the shoulders, back, and legs can cause more or less chronic sore muscles states, the seat of the pain probably being in the muscle connective tissue. How these conditions develop is not well known, but permanent overloading of small, discrete parts of the muscles is probably the most common cause. Whether the ensuing condition of soreness, oedema, and local hyperaemia is caused by anaerobic metabolites or results from a reaction of the connective tissue is not known. The latter seems the more probable because of the resemblance of the signs and symptoms to those developing 24-48 hours after local overloading of the muscles in untrained persons and in experimental animals (22, 23).

Proper training will also strengthen the connective tissue in the muscle and may thus act as a prophylactic. In this connexion, it is also necessary to point to the great importance of being able to relax the muscles. Specific relaxation exercises are in common use.

One of the most common causes of disability among adults, especially in the older age groups, is pain in the back. In a great many cases this may be caused by back muscles that are too weak.

Obesity. The relation of physical activity to obesity has been the subject of extensive studies both in experimental animals and in man. Obesity is not a uniform syndrome. The imbalance between calorie intake and expenditure may in many cases be ascribed to reduced activity and to a deficient adjustment of the appetite to calorie needs. There is substantial evidence that sufficient habitual occupational or leisure-time activity prevents obesity (24, 25).

Diabetes. In mild diabetes and in the diabetes of older people regular physical activity improves the metabolism and in some cases facilitates control by medication. Diabetic children need regular physical activity in daily life. If they are not excluded from school sports and other training facilities, they may develop the same aerobic power in relation to body dimensions as healthy children (26, 27, 28).

Other organ systems. The functional variables of the respiratory system are closely correlated with body dimensions. However, training may also affect them. This is shown in the increased maximum voluntary ventilation, vital capacity, and diffusing capacity of the lungs of athletes (29).

Pulmonary function deteriorates with age. It has been observed that age changes are retarded by physical activity (30).

The incidence of some pulmonary diseases is smaller in sportsmen than in the general population (31). Physical activity does not prevent pulmonary tuberculosis. On the other hand, remedial exercises have an established place in the treatment of many pulmonary diseases.

Training causes an increase in both the blood volume and the total haemoglobin. The haemoglobin concentration, however, either remains constant or decreases slightly. Both the coagulability of the blood and fibrinolysis increase during exercise (32). The change in coagulability, however, is less pronounced in physically trained subjects at the same exercise load.

The effects of physical activity on female reproductive function have been the subject of several studies. It has been reported that irregular menstrual cycles have been normalized and dysmenorrhoea relieved as a result of regular exercise. On the other hand, exhausting exercise and over-training may cause transitory menstrual irregularities and even transitory amenorrhoea.

The course of pregnancy and delivery is not adversely affected by physical activity. A lower incidence of complications has, in fact, been reported in women engaging in sport (33).

Heavy exercise during pregnancy taxes the cardiovascular reserves and may restrict the uterine blood flow, particularly towards the end of pregnancy. This factor may become critical, especially in mothers with a small total blood volume and small aerobic power. The incidence of premature delivery has been found to be highest in some populations among mothers in whom a small heart volume was observed radiographically during the early part of pregnancy. When mothers with small hearts were given advice to avoid severe exertion during the last trimester, a marked decrease of the incidence of premature deliveries was observed (34, 35).

MAXIMUM AEROBIC POWER

Principles of measurement

Maximum aerobic power is assessed by measurement of the maximum oxygen uptake attained in dynamic muscular exercise. It can be measured directly or indirectly. Direct measurement is based on performing muscular exercises with increasing intensity and establishing a work rate above which a further increase in work output does not bring about a higher oxygen uptake. This levelling off of oxygen uptake is used as a criterion of the maximum value. Indirect measurement is based on establishing a linear relationship between the heart rate and the oxygen uptake measured when the metabolic rate, circulation, and respiration have reached the steady state at submaximal work, and with subsequent extrapolation to the maximum heart rate. Empirically established age-dependent mean maximum values for a given population are often used as an approximation for the maximum heart rate.

The indirect method can be simplified by establishing the linear relationship between the work rate (e.g., on a bicycle ergometer) and the heart rate, with a subsequent extrapolation to the maximum heart rate. In this way the work rate corresponding to the maximum oxygen uptake can be estimated.

The values of maximum oxygen uptake depend on the type of exercise used in the test. The critical muscle mass that has to be activated in order to measure the " true " maximum value cannot be stated at this time. Pedalling a bicycle ergometer, stepping, or walking and running are activities commonly employed. Within certain limits, those methods give comparable results. Details about the methodology may be found in the literature.

Factors influencing the level of maximum aerobic power

The maximum aerobic power of an individual is mainly determined by his inherited constitution, but a number of environmental factors are known to modify it. Maximum oxygen uptake is usually expressed in absolute values (as 1/min), or in relation to body size (as ml/min per kg body weight or as ml/min per cm body height), or as a multiple of either the resting or the basal metabolic rate. The problem of maximum oxygen uptake in relation to body size is dealt on page 21.

Effect of age. Age exerts a considerable influence upon the maxi. mum aerobic power, as has been established in a number of populations- Absolute values increase during childhood and adolescence at approximately the same rate as the weight and height. The peak values are reached in early adulthood. In man, a gradual and steady decline with age takes place from the age of 25-30, and at the age of 70 years the maximum aerobic power is about 50 % of that at 20 years. For women, the peak value is reached closely after maturity; the absolute value remains fairly constant during the fertile part of life, after which it declines at about the same rate as in men.

Sex differences. In early childhood there are no sex differences in aerobic power. At the onset of adolescence a divergence takes place, resulting in higher values for boys, and at the end of adolescence the maximum aerobic power per kg of women is only about 70 % that of men.

Ethnic differences. Only a few studies have been performed in which the subjects were selected according to ethnic origin and the methods used were comparable. Present knowledge on the subject suggests a great similarity in aerobic power between the various ethnic groups.

Not only do they average about the same, but the variability measured by the standard deviation is also quite similar, giving a variability coefficient for the maximum aerobic power per kg body weight of about 10 %.

Small but significant differences, however, have been established between populations with different genetic backgrounds. At present it is impossible to state to what extent such differences are genetically or environmentally determined.

Effect of climate. Short-term exposure to heat or cold does not appear to create differences in the maximum aerobic power. Differences, however, are observed between arctic and tropical populations, the former having higher values at all ages and in both sexes (36).

Effect of nutrition. A number of experimental studies on man have shown that undernutrition and malnutrition reduce the maximum aerobic power which, however, is quickly restored to its normal value when the food supply becomes adequate.

Effect of hypoxia (altitude). When sea-level dwellers are exposed to altitude, there is no deterioration in their maximum oxygen uptake up to an altitude of 1200-1800 m. From then on a deterioration takes place at a rate that increases with the altitude. At 3000 metres the reduction is about 20 %.

Acclimatization to altitude can take place, involving compensating mechanisms, so that the performance capacity is improved after a few weeks of dwelling at high altitudes. Acclimatization is known to proceed for at least a year, but it is doubtful if full compensation can be acquired within a man's lifetime, even at a moderate altitude (2000-2500 m).

Populations that for generations have adapted themselves to a life under hypoxic conditions have bodily characteristics making them particularly fit for work at high altitudes. A comparison between genetically similar lowland and high altitude populations (3000 m) has revealed a similar maximum aerobic power in these two populations when tested in their own environments.

Habitual physical activity. In the clinically healthy well-nourished man, the level of habitual physical activity is probably the most important environmental factor influencing maximum aerobic power. The effect of training is dealt with on page 22, but the level of maximum oxygen uptake in population groups that differ with regard to habitual physical activity deserves attention.

There are great differences in the energy requirements of different occupations. The results of studies of the relationship between the maximum oxygen uptake of workers and their occupational energy expenditure reveals a great similarity between workers in occupations requiring different levels of energy expenditure. Lumberjacks, for example, average only 10-15 % above office workers. This difference may, at least partly, be attributed to selection.

Considerable information is available about the maximum aerobic power of athletes. Athletes who compete in endurance events have a maximum aerobic power of up to 80 % above the average of sedentary people. Athletes are certainly a highly selected group, probably with distinct genetic characteristics.

Leisure-time activity may be very high in some population groups of industrialized societies. Comparisons have been made between groups of middle-aged men in professions requiring a low level of energy expenditure. One group was physically extremely active during its leisure, the other more sedentary. The results revealed a 30 % superiority in maximum aerobic power in the group given to more physical activity, but again selection may have played a role.

Pathological conditions. Considerable evidence is available to demonstrate the deterioration in the maximum oxygen uptake in acute and chronic disease. This deterioration may be a result of special pathological conditions but is also due to physical inactivity, as when a patient is bedridden.

It has been demonstrated that, when the maximum oxygen uptake is reduced by acute diseases or injury, it can be quickly restored to a normal value by a rehabilitation programme involving physical exercise.

Standards for maximum oxygen uptake

It is impossible at present to indicate an optimum level of maximum aerobic power for health in general. This problem obviously has many facets, of which the most important is the correlation of aerobic power with cardiovascular disease and with longevity.

One approach is to relate the maximum aerobic power to occupational requirements. It is clear that occupational activities requiring a high energy expenditure must be undertaken by workers with sufficient aerobic power. Empirically, work physiologists have reached the conclusion that occupational activities should not employ more than 30-50 % of an individual's maximum aerobic power. There are, however, in modern industry very few occupations that even during peak activities require energy requirements greater than 15-25 % of the maximum aerobic power. This may therefore not be a very fruitful approach to the setting up of reference standards for maximum aerobic power.

A better basis for setting up standards may be the use of results from population studies. It has repeatedly been shown that the maximum aerobic power, like many other functional characteristics of the body, is distributed normally in a healthy population (37). The average value in a particular population or population group may thus be used as a reference standard and the result of individual testing may be related to this value. The coefficient of variation of maximum aerobic power per kg body weight is approximately 10 %.

It should be realized that standards have to be established for various ethnic and population groups. It is hoped that results from current investigations within the International Biological Programme will contribute to this.

MUSCLE STRENGTH

Muscle strength is an expression of the maximum voluntarily mobilizable force that a muscle group can produce under certain conditions. These conditions are partly dependent on the subject — on, for example, his will or ability to exert himself to the maximum. Such factors as lack of motivation or pain in the muscles or joints may limit his exertions and thus his mobilizable muscle strength.

Other conditions depend on the procedures used in measuring muscle strength. Among these must be mentioned the kind of muscle activity that is used when measuring dynamic strength and static or isometric strength. Dynamic strength is characterized either by shortening of the muscles during contraction (concentric contraction) or by lengthening of the muscles by some outside force such as gravity, the investigator's activity, or a specific instrument. In the latter case the muscles resist the outside force, and their contraction is called eccentric. In isometric measurements no movement or only negligible movement occurs. It is of great importance to standardize the position of the various anatomical levers that transfer the force exerted by the muscles to the measuring apparatus. Failure to do so may lead to erroneous impressions of strength, the errors sometimes amounting to more than 50 %. Easily reproducible positions are to be preferred, even if greater force can be produced in other positions difficult to define.

Experiments have shown that the types of strength — concentric, eccentric, or isometric — measured under the conditions mentioned above are closely correlated. They have also shown a systematic difference, inasmuch as strength in concentric is less than in isometric contraction in identical positions, and strength in eccentric is greater than in isometric contraction. These differences depend on the speed of movement in the two dynamic conditions, and may in rapid movements amount to more than ± 40 % of the isometric. For this reason alone, isometric measurements are to be preferred. Further, by using dynamometers the equipment necessary for isometric measurements can be made quite simple and versatile. A standard set of dynamometers, using electronic strain gauges, has been developed at the Danish National Association for Infantile Paralysis, Hellerup, Denmark (38), but several other types also exist.

Muscles strength is measured, either in kgf [1] or, on special occasions, in kgf × cm, i.e., in torques. In adults it depends on several factors : body size, sex, age, state of training, and inherent factors. The last two may account for the large variation found in groups of people in whom the other factors have been equalized, giving standard deviations of ± 15 - 20 % in the measured strength of normal subjects.

Body size influences muscle strength mainly by increasing the sectional area of the muscles. It has been found repeatedly that the strength of a muscle group, expressed per cm^2 of the sectional area, is nearly a constant (39). Muscle strength would consequently be proportional to the square of the body height if people of different heights were similar in build. An increase, say from 160 cm to 176 cm, in total height — 110 % of the original height — would give an increase of 121 % in muscle strength. Besides body height, body type also plays a role in muscle strength. It has not been studied extensively in adults, but in children it has been found that those belonging to the broader type were markedly stronger than their more slender counterparts.

The sex difference found in muscle strength is partly due to the different average height of men and women and partly to qualitative differences. On an average, the muscle strength of adult women is about 65 % of that of men. After elimination of the height difference, the strength difference is reduced so that women have about 80 % of the strength of men of same height and age.

Age plays an important role in muscle strength. It appears that the greatest muscle strength is attained at about the age of 30 years. From then on it decreases, more in the trunk and lower extremities than in the hands and arms. At the age of 65 years it is 80-90 % of the value at the age of 25 years in men, or less, and 70-80 % or less in women (40).

The state of training influences muscle strength. It must especially be mentioned that prolonged periods of inactivity greatly reduce muscle strength. The large muscle groups of the trunk and lower extremities are most susceptible to inactivity, so that extremely low values may be encountered in patients entering upon medical and vocational rehabilitation.

Standard values

Comparable values for muscle strength are difficult to find in the literature, mainly due to the difficulties in comparing results obtained

[1] 1 kgf = 1 kilogram force, the force with which gravitation pulls on the mass of 1 kg.

by different procedures and methods. A set of standard values from 25 different muscle groups, based on measurements on 360 men and 250 women aged 15 to 65 years, was published by the Danish National Association for Infantile Paralysis in 1961 (41).

The maximum isometric strength of the back muscles, measured in 600 normal men and women in the age groups 15 to 65 years, was 60 to 100 kgf in men, 40 to 65 kgf in women. The strength decreases from about 30 years of age on.

Optimum muscle strength

When the optimum level of muscle strength is discussed in relation to health, the erector muscles of the spine deserve special attention. Theoretical minimum values of the strength of these muscles can be calculated for two " situations ", expressed in relation to body weight.

Situation 1. Much activity is involved in maintaining an upright, slightly forward, stooped position. The forces acting on the back in this position and the minimum muscle strength of the erectors of the spine necessary to enable the subject to maintain this position for prolonged periods of time are as follows.

Let W be the body weight, and 0.5W the weight of the body parts above the iliosacral joint. Let the centre of gravity for these body parts be situated at a point two thirds of the distance from the iliosacral joint to the shoulders. The pull of gravity will be 0.5W at the centre of gravity. Transferred to the height of the shoulders, it will be $0.5W \times 2/3$. Assuming the forward tilt of the body to be 15° (sin 15° is 0.25) the part of the gravitational pull that acts perpendicularly to the body axis will then be $0.5W \times 2/3 \times \sin 15°$. This is the force that must be equalized by the backward pull of the erector muscles of the spine at shoulder height.

For this force to be maintained indefinitely, it should constitute only, say, 12 % of the maximum force that the muscles of the spine can produce (41, 42). The maximum isometric strength of the erector muscles of the spine should consequently exceed $0.5W \times 2/3 \times \sin 15° \times 100/12$, or about 2/3W. For a person weighing 60 kg, therefore, the erector muscle strength should exceed about 40 kg.

Situation 2. For lifting loads in the hands the following situation can be imagined. It is assumed that the lifting is performed properly, i.e., with the back in a normal straight position, tilted 45° forward. For simplicity it is assumed that half the body weight (0.5W) and the weight of the burden *a* pull together in a vertical direction at shoulder height.

The pull of gravity will be $(a + 0.5W)$ and its forward directed component, perpendicular to the body axis, will be $(a + 0.5W) \times \sin 45°$. This component must be overcome by the pull of the erector muscles of the spine in the opposite direction, the force required being [$a \times \sin 45° + 0.5W \times \sin 45°$]. As sin 45° is 0.7, this becomes [$0.7a + 0.35W$]. Further, if P_{max} is the maximum isometric strength of the erector muscles of the spine, the force available for lifting must be [$P_{max} - 0.35W$]. This means that, to lift burdens, the maximum spinal muscle strength must exceed about one third of the body weight. The weight lifted will be this difference divided by 0.7 (= sin 45°), or 1.4 × the difference between the maximum strength and one third of the body weight.

Example 1 : Body weight 60 kg; maximum isometric back strength 50 kgf.

$1.4\,[50 - (1/3 \times 60)] = 42$ kg
i.e., up to 42 kg can be lifted.

Example 2 : To lift 30 kg when the body weight is 60 kg.

30 kg = $1.4\,[X - (1/3 \times 60)]$. X is therefore 48 kg and the muscle strength of the erectors of the spine should exceed 48 kgf.

This calculation is a theoretical approach to the overall problem. Further experimental laboratory work is necessary to prove its applicability.

BODY COMPOSITION AND SIZE IN RELATION TO PHYSICAL PERFORMANCE CAPACITY

Body composition

The relationship of maximum aerobic power to major components of the body has been assessed by many investigators. In general, high correlations have been found between maximum aerobic power and lean body mass, total haemoglobin, total body water, and total body potassium. The ratio between lean body mass and total body weight undergoes changes during the processes of growth, development, and aging and also shows significant sex differences.

Changes in body composition under training may take place without noticeable changes in body weight, e.g., lean body mass may increase at the expense of fat. When training is discontinued, body weight may increase solely because of the deposition of fat.

The following methods are used in assessing body composition (43, 44) :

(*a*) measurement of body density;
(*b*) measurement of skin fold thickness;
(*c*) measurement of total body water and potassium content;
(*d*) ultrasonic measurement;

(*e*) measurement by hydrostatic weighing and by volumetric determination of " lean leg " volume from X-ray pictures.

While all these methods have proved useful in estimating body composition, it appears that, for practical reasons, only the skin fold method can be recommended for field surveys. However, in using skin fold thickness methods in population studies it is necessary to standardize the method for different population groups, since the localization of the subcutaneous fat may vary. The variation is largely due to individual inherited characteristics and is determined by genetic factors.

More information is required on the mechanisms involved in the shift in body composition from fat to lean body mass as a result of training, in order to elucidate the factors regulating these shifts — genetic and/or acquired (as the effect of different occupational and cultural habits).

Body size

It is quite evident that a big motor can perform more work than a smaller one. Correspondingly, a big body is able to develop more energy, to perform more work, and to exert more mechanical force than a smaller body. This needs to be taken into account in the evaluation of a person's PPC.

When a person's PPC is considered in terms of, for example, work on a farm or in a factory, the most important factor is the absolute amount of energy and force he can produce. Here big size is naturally an advantage. When it is considered in terms of his health, it is his relative PPC that must be taken into account, in relation to some relevant body measure. For a theoretical evaluation of what parameters should be used for expressing the relative values of PPC, it can be assumed that adults, irrespective of their size, are geometrically similar. Total body height can be taken as the basic expression for size, and the general body composition may be assumed to be constant. It follow from these assumptions that all linear dimensions in the body are proportional to height (h), all areas to h^2, and all volumes and weights to h^3.

Physiological and anatomical measures such as body surfaces and intestinal surfaces will increase with body height in proportion to h^2. Sectional areas of, e.g., the muscles, vary in the same way, and a function like muscle strength also increases with h^2. Volumes such as lung volumes, heart volumes, and blood volumes and weights such as total body weight, muscle mass, and limb mass vary with h^3. In functions expressed per time (t) unit, as in heart frequency, respiratory frequency, and aerobic power, it follows that t must be proportional to h from the equation $f = m \times g$, expressed on a dimensional scale with f (muscle force) proportional to h^2, m (mass of heart, limbs, etc.) proportional to h^3, and g proportional to $h \times t^{-2}$.

In running, for instance, step length must be proportional to h, but the time used for each step is also proportional to h. Step frequency will consequently be proportional to h^{-1}, and the speed of running (= step length × step frequency) will turn out to be independent of height.

Whether a similar simple relationship holds for aerobic power (ml/second) has not been clarified. If it does, aerobic power should be expected to be proportional to h^2 (h^3/h), and the proper way of expressing its relation value should not be per kg body weight or lean body mass, but rather per m^2 body surface or per body height squared.

These theoretical considerations are meant to emphasize the importance of the effect of body size on PPC and of choosing the right parameters in expressing the relative values of PPC.

ANTHROPOMETRIC AND HAEMODYNAMIC VARIABLES

Apart from age and sex, the following anthropometric variables show a significant correlation with maximum aerobic power in healthy subjects : (1) body size (weight, height); (2) body composition; (3) total haemoglobin; and (4) heart volume. Variables (3) and (4) incorporate the variations due to differences in sex, average level of physical activity and, to some extent, age. It is possible with the aid of these variables to predict normal values for maximum aerobic power and to define the limits of normal variation. In this way normal values for the relationship between aerobic power and body size, heart volume, and blood volume have been collected in different countries. The specificity of such normal values for the population studied is stressed (45, 46, 47, 48).

The following haemodynamic variables determine the maximum aerobic power : the heart rate, the stroke volume, and the arteriovenous oxygen difference for the whole body. The relationship between the maximum aerobic power and these variables is expressed by the Fick equation for oxygen transport :

$$\left(\dot{V}_{O_2}\right) \max = F.SV.AVD,$$

when $\left(\dot{V}_{O_2}\right) \max$ = maximum aerobic power

F = heart rate

SV = stroke volume

AVD = arteriovenous oxygen difference.

$\left(\dot{V}_{O_2}\right) \max$ is reached when the combination of these variables is optimal (49, 50).

Variation in the heart rate, stroke volume, and arteriovenous oxygen difference with oxygen uptake depends on such factors as the type and duration of work, environmental temperature, the water and electrolyte balance, and the PPC.

In steady exercise of short duration (<10 min), the heart rate is linearly related to the oxygen uptake almost up to the maximum heart rate, when the line may flatten out. The stroke volume usually increases on the transition from rest to work, the magnitude of the increase being mainly determined by the distribution of the blood volume within the capacitance vessels. When work is continued, the stroke volume remains unchanged up to the maximum levels of work intensity. Most of the available data seem to indicate that there is no further increase in the stroke volume; moreover, a slight decrease is possible (50). The magnitude of the stroke volume is determined by the size of the heart (radiographical heart volume) and the filling and emptying of the heart.

The arteriovenous oxygen difference (AVD) varies hyperbolically with the oxygen uptake. The course of the hyperbola is determined by such factors as the size of the stroke volume, body position, age, degree of training, and vasomotor regulation (49).

The product of the heart rate and the stroke volume, i.e., the cardiac output, varies linearly or slightly curvilinearly with the oxygen uptake. The slope of this line varies little between individuals as long as the stroke volume does not vary during exercise. The *intercept level* of the line is determined by the same factors as those which determine the position of the AVD hyperbola, i.e., the stroke volume in relation to the size of the cardiovascular system (blood volume), body position, age, haemoglobin concentration, state of training, and vasomotor regulation (50).

During long-term exercise (e.g., one hour at 50 % of maximum capacity) a steady cardiac output is maintained in a neutral climate. The other variables of the Fick equation vary with time. The heart rate increases and the stroke volume decreases either due to impaired filling of the heart as a consequence of venous pooling or to a change in the ability to empty the heart (50).

Information on the haemodynamic response to various types of intermittent exercise is scarce. Studies are in progress in many countries and much further research is necessary.

TRAINING

Physical training increases the PPC and each of its elements.

Each element requires a specifically adapted training programme.

Training for aerobic power

To train aerobic power two methods are available : continuous training and intermittent or interval training. From trans-sectional studies it is known (46, 48) that athletes with a high maximum aerobic power have an oxygen transport system of large dimensions (lung volume, volume of the vascular bed, blood volume, total haemoglobin, heart volume, cell mass) and that the different components of the oxygen transport system have large functional capacities (ventilatory capacity, diffusion capacity, cardiac output, stroke volume).

The magnitude of the increase depends on the initial state of training. The effect of training is inversely related to this initial state and depends on the intensity of the training and the duration of the training period.

From longitudinal studies it is known (51) that physical training involving large muscle groups that load the oxygen transport system to at least 70-80 % of the maximum results in an increase in maximum aerobic power. The lowest level of training that increases maximum aerobic power is not known, and the duration of training needed at different work loads is incompletely known.

Maintenance of physical performance capacity

The amount of training necessary to maintain an achieved increase in the PPC is dependent on the relative magnitude of the increase. A daily training of 30 min at 70 % of the maximum causes an increase in aerobic power that can be maintained by three training periods per week of 30 min at 70 % of maximum capacity. Research in this area is in progress and is of practical importance.

Sporting activities and training in youth have an effect on the PPC only during the training period and for a short time afterwards. They have not been shown to have any influence on growth and development in youth, and all the changes brought about by training in many physiological functions and dimensions of the organism decrease immediately after the end of the training. Therefore sporting activities in youth appear to be useless in relation to the PPC at a later age if they are stopped at the end of adolescence. Sport and physical education, however, not only change the habits of daily life in relation to physical activity during the training period but may induce habits that remain for a longer period of life. From this point of view, it is one of the duties of physical education to teach young people activities they will be able to continue after having finished school and to motivate them to do so.

The effects of physical training on the oxygen transport system can be divided into two groups — regulatory and dimensional. Regulatory changes are obtained within weeks and consist of : (1) a more effective distribution of the blood flow so that the same amount of oxygen is transported with a smaller amount of blood; (2) an optimization of the filling conditions for the heart by stabilization of the capacitance vessels; (3)

possibly a change in the contractibility of the myocardium. These regulatory effects of training appear and disappear rapidly and probably explain day-to-day variation in physical fitness.

The dimensional effect of training consists of an increase in the size of the different components of the oxygen transport system (lung, blood, and heart volume). The dimensional effect is achieved in two stages. The first consists of increases that occur within the same time period as the regulatory effects, the second of a slow growth of the oxygen transport system. They can be measured as an increase in the heart volume (as seen by X-ray), the lung volume, the blood volume, and the total haemoglobin. These changes occur when the training is continued for a long time (months or years) and depend upon the age of the subject.

Training and circulatory response to exercise

The increase in maximum aerobic power that occurs during training is brought about by loading of the oxygen transport system and is due partly to an increase in the arteriovenous oxygen difference and partly to an increase in the stroke volume that results in an increased maximum cardiac output (51).

During submaximum work such training results in a fall in the heart rate, cardiac output, and blood lactate levels for a given oxygen transport. The systemic blood pressure may remain unchanged, or increase or decrease slightly. The effect is to reduce the work of the heart in transporting a given amount of oxygen (51).

Trainability in relation to sex, and age, and fitness

The development of aerobic power by training depends on the age of the subject. Old subjects show a smaller but significant increase in aerobic power when exposed to the same relative intensity of training. The intensity of training should involve 70 % of the maximum aerobic power; 50 % may not cause an increase in old subjects. Trainability is of the same relative magnitude for both sexes.

Training for muscle strength

Training for muscle strength must be considered from two points of view. One is the increase of the cross-sectional area of the muscle, the other the increase in the number of mobilizable motor units and nervous impulses to the muscle fibres (52).

To increase the cross-sectional area of the muscle, submaximum weight training, applying for example 2/3 of maximum strength, is recommended. The results appear gradually over a period of several weeks.

To increase nervous impulses to the muscles, weight training applying maximum strength is required. The effect will be noticed within a week. This is shown by the measurement of strength per unit cross sectional area of the muscle and by the maximum strength developed by individuals during the course of training. The increase in strength per unit cross-sectional area observed in the early stage of training is followed by an increase of the cross-sectional area of the muscle in the later stages (39). Muscle training for adults should be increased progressively, starting with submaximum loads.

It is now generally agreed that it is a slow process to increase the isometric strength of a weak but otherwise normal muscle group. Even with heavy loads and many daily repetitions, an increase of only 2-3 % per week must be considered the limit (53, 54). There are, however, several aspects of muscle strength performance that must be considered These may be listed as : (*a*) isometric strength, (*b*) dynamic strength — a measure of the maximum work performed in one contraction, (*c*) static endurance and (*d*) dynamic endurance. The latter two are expressed respectively as the time a certain percentage of maximum force can be maintained and the highest number of contractions with a certain load that can be performed. Experience shows that the training procedure acts differently on these functions (55, 56). Generally it may be stated that isometric and dynamic training with comparable loads and frequencies have about the same training effect on isometric strength. Static (or isometric) training, however, increases static endurance but not to any considerable degree dynamic strength or endurance. Dynamic training (e.g., weight lifting) increases dynamic strength and endurance but not static endurance. The reasons for this specificity of training are still obscure, but from the experimental findings it is clear that dynamic training is the most profitable.

Training of neuromuscular co-ordination

For neuromuscular co-ordination it has been shown that training with frequent interposed rest pauses clearly gives a better effect than continuous training without such pauses.

Practical recommendations for training

Although, so far, only a few aspects of the problem of using physical training as a means of strengthening health and preventing illness have been sufficiently well studied, the research already carried out and the experience of work in this sphere gained in a number of countries make it possible to put forward a number of practical recommendations.

Two different ways of utilizing the effect of muscle activity with the aim of stimulating the function of the organism should be distinguished — physical training and active recreation during working hours.

The training process and its effects on the organism are being studied by physiologists in experimental animals and in man. Research on training has been carried out and a substantial amount of empirical knowledge on training methods contributed also by specialists in sports medicine, physical medicine, and rehabilitation, as well as by physical educators and by sports coaches. When training programmes are planned, it is obviously advisable to draw on the combined expertise of all these specialties.

Giving training on a large scale to previously untrained middle-aged or elderly people with various handicaps poses special problems in leadership. A substantial number of group leaders are needed with skills derived from medicine, physical education, sports coaching, and exercise therapy. This need is also felt for patients who already suffer from conditions such as ischaemic heart disease and arthritis in which the long-term management must be carefully adapted to individual needs and possibilities.

Information on physical training and its effects should also be included in health education programmes. Training that does not primarily aim at athletic accomplishments can be carried out by organizing health groups for persons above the age of 30.

Gymnastics and athletic exercises, skiing, skating, swimming, games such as volley-ball, basketball, tennis, and badminton, cycling, and rowing may be the subject of group and individual physical training sessions. A particularly expedient method is a combination of exercises such as gymnastics, athletics, swimming, and other sports.

The basic principles of physical exercises for people of mature age, middle age and, especially, old age are strict grading of the amount and gradual increase in the physical exertion and in the regularity of the training sessions. The grading of the amount of physical exercise should take into account three factors : the intensity, duration, and frequency of the training sessions.

The intensity of the exercises should be submaximum. For middle-aged people (45-59) and older people (60-74) the permissible load should not exceed 60-70 % of the maximum performance capacity. The load should be lower when age-conditioned changes and disturbances in the organism's adaptation to muscle activity are more pronounced.

A thorough medical examination of persons entering training is desirable and should include functional and motor testing. On the basis of the examination people entering training may be divided into groups, to secure appropriate training for each subject.

To judge the correctness of the chosen training technique, it is advisable to carry out tests during the sessions that would permit the detection of abnormal reactions to the various physical exercises and to introduce any necessary corrections in the methods of training.

Most exercises should be considered feasible for middle-aged and elderly persons, if they have no pronounced disorders. By introducing them in graded amounts in the training session, it is possible gradually to bring in strenuous exercises such as running. Athletic competitions involving considerable physical effort and psychological tension should, however, be excluded for elderly people. Middle-aged people may participate in competitions of this kind in their own age group, after training lasting 4 to 6 months.

Exercise programmes should be designed to be attractive and enjoyable to people of the age concerned. In order not to make the participants too conscious of their health, the health aspects of the programme should not be overemphasized.

ACTIVE RECREATION AND COMPENSATORY EXERCISE DURING WORKING HOURS

Working conditions in modern society are generally characterized by gradual elimination of physical effort and by increasing mental strain. This development must be considered when establishing requirements for rest and recuperation. Setschenow (57) has shown the favourable influence on the recovery of fatigued muscles of exercising other muscle groups. In some countries good results have been reported with special types of gymnastics on the shop floor during rest pauses. Special regimes of this type improve many bodily functions and the productivity of the worker.

The special features of active recreation distinguish it in many respects from physical training. The primary aim of active recreation is not to increase the PPC but to eliminate fatigue, to improve productivity and health, and to prevent accidents at work (58, 59). Its importance becomes greater with increasing age (60).

The results of active recreation were obtained under industrial conditions that may not be present in all factories. Therefore, before applying them to other industries, the best method has to be determined by medical experts.

Further research is needed into the short-term and long-term effects of active recreation during rest pauses on bodily function and the general health.

RECOMMENDATIONS

1. To establish the intensity, duration, frequency and type of physical activity required to attain and maintain optimum health and well-being and to meet the occupational and recreational demands of everyday living, the Group recommended that research should be carried out:

(*a*) To compare the effectiveness of different training methods in improving the various components of physical performance capacity;

(*b*) To establish the preventive and therapeutic value of physical training in disorders of the musculoskeletal system;

(*c*) To establish the preventive and therapeutic value of physical training in various disorders of the digestive system;

(*d*) To establish the effect of physical training on the mechanisms involved in shifts in body composition;

(*e*) To study the biochemical, biophysical, and physiological mechanisms involved in static and dynamic muscle training;

(*f*) To evaluate the suitability of physical exercise and sports programmes for people of all age groups in different populations;

(*g*) To develop methods of measuring anaerobic power and capacity and of identifying the limiting factors;

(*h*) To identify the factors necessary for endurance performance at different levels of work intensity and to assess quantitatively their relative importance, as well as to develop methods for predicting aerobic endurance capacity without actual performance of the task over the total required period of time;

(*i*) To establish quantitative relationships between anthropometric variables (with special emphasis on somatotypes) and physical performance capacity;

(*j*) To establish the relationship between type of personality, as defined by psychological characteristics, and physical performance capacity;

(*k*) To validate optimum muscle strength, as calculated theoretically on page 18;

(*l*) To determine the proper way of expressing maximum aerobic power so as to evaluate its relation to health factors (ml o^2/min per kg body weight, per kg lean body mass, per m^2 body surface, or per body height squared);

(*m*) To establish the haemodynamic response to various types of intermittent physical exercise;

(*n*) To develop a practical method of measuring habitual physical activity;

(*o*) To establish the relationship between habitual physical activity and physical performance capacity;

(*p*) To assess the influence of the qualitative aspects of diet on physical performance capacity.

2. The inclusion of standard tests for physical performance capacity in routine medical examinations should be promoted in countries where standards can be established on the basis of the population studies available.

3. Population studies should be carried out by standard methods for the assessment of the maximum aerobic power and muscle strength that can be used as a basis for standards of physical performance capacity in each country.

4. The relationship between age and maximum heart rate in different populations should be established so that the submaximum exercise technique for the determination of maximum aerobic power can be used.

5. Data should be collected on maximum aerobic power and maximum aerobic power per kg body weight of comparable population groups in different parts of the world (if possible also with a comparison of values of the recent past with the data collected, if there is reason to believe that the maximum aerobic power in absolute values or per kg body weight is changing as a result of modern civilization).

6. Attempts should be made:

(*a*) to establish the relationship between indices of physical performance capacity and different parameters of health by population studies (longitudinal as well as cross-sectional), in order to work out the optimum levels for physical performance capacity;

(*b*) to establish the relationship between physical performance capacity and longevity;

(*c*) to establish the relationship between physical performance capacity and the rate of deterioration of other body functions with age.

7. Epidemiological studies should be carried out of cardiovascular disease prevalence, incidence, and prognosis among populations of lifelong physically active habits. As these populations may be rather dispersed, such studies should be carried out through collaborative efforts.

8. Controlled " intervention " studies should be carried out to establish whether the assumption of physically active leisure-time habits by middle-aged men affects their ischaemic heart disease experience and susceptibility to other diseases. Since such studies are feasible only among a population that co-operates sufficiently but are of interest also to countries where subjects cannot be recruited with equal ease, the studies should receive wide support.

9. Studies of the health of athletes should be continued after the cessation of the competitive period. It is recommended that WHO continue its co-operation with the Olympic Medical Archives in that respect.

10. All the results from different countries of population studies on the various aspects of physical performance capacity should be collected and published.

11. A manual should be prepared on methods of measuring muscle strength and related aspects of physical performance capacity.

12. The study of the physiological and medical aspects of physical activity and various aspects of physical performance capacity should be introduced into the curriculum of medical schools and of the appropriate schools for paramedical personnel.

13. Fellowships should be established for the training of physicians and research workers in the techniques related to the various aspects of physical performance capacity, and of personnel in the performance of anthropometric measurements using standard methods in somatotypology.

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