Energy metabolism

INTRODUCTION

Energy is the capacity to do work. A HEALTHY person is also ENERGETIC and usually enthusiastic. Where does this energy come from? A person who is well-fed appears to possess nearly unlimited energy whereas an inadequately fed person seems to be tired all the time. Hence a person derives ENERGY from the FOOD he consumes.

UNIT OF ENERGY

CALORIE is the unit of energy. It is defined as the quantity of heat required to raise the tempera- ture of ONE g of water by ONE DEGREE C. (14.5-15.5°C). However, this unit is too small for measuring energy in NUTRITION; a Kilo-Calorie (I Kcal=1000 cal.) is used. The International Union of Nutritional Sciences (IUNS) has adopted the JOULE, 4.184 J being equal to 1 cal, as the unit (1 Kcal 4.184 KJ).

BASAL METABOLIC RATE (BMR)

Even when a person is not working, a certain amount of energy is required for life-sustaining activities like respiration, blood circulation, brain function, functioning of the digestive system and so on. All these constitute 'Basal Metabolism' or the more recently used term 'Resting Energy Expen- diture' (Table 1). For example, the brain expands 19% of BMR. This energy requirement is more precisely defined by fixing some of the parameters, which influence BMR. The Indian Council of Medi- cal Research (ICMR) has defined that: 1) The Reference Man is 20-39 years of age and weighs 60 kg.. and the Reference Woman is 20-39 years of age and weighs 50 kg. And both are physically fit and free from disease.

No	Organ	Energy as % of BMR (approx.)
1	Brain	19
2	Heart	10
3	Kidney	7
4	Liver	29
5	Skeletal muscle (at rest)	18

Table 1. ENERGY EXPENDITURE OF ORGANS

BMR is measured under the following conditions. The patient should be:

1) In the post-absortive state i.e., should not have eaten anything during the past 12 hr.

ii) relaxed physically and mentally-usually a One-Half Ilour bed rest before the test.

Skeletal muscles (at rest)

iii) in a recumbent position,

iv) awake and

v) in an environmental temperature of 20-25°C.

BMR is determined by calorimetry. In direct calorimetry, the heat produced by the body is measured by circulating a current of water and determining the raise in temperature and computing the quantity of heat. In indirect calorimetry, the energy is calculated on the basis of oxygen consumption by the person housed in a Respiratory Calorimeter.

BMR is usually expressed as kcal/m^3/hr. (approx. 40)

Factors influencing BMR

Basal Metabolic Rate is influenced by Age, Sex, Surface area of the body, Nutritional status, by Disease and by Hormones.

Age: The BMR is low in the new-born; it attains the maximum at about 5 yrs. of age and then there is a decline continuing into old age. However, just before puberty there is a relative rise. The BMR is about 50 Kcal/m2/hr at abut 6 yrs; at 21 yrs it is around 38 Kcal/m^3/hr.

Sex Women have a lower BMR than men. Further between 5 and 17 yrs of age, the BMR for females decreases mare rapidly than for males.

Surface Area: The BMRs of larger individuals are higher than those of smaller individuals. Also, the major determinant of BMR is the Fat-Free Mass or 'Lean Body Mass'.

Nutritional status: BMR is lowered by starvation or undernourishment.

Diseases: Infectious diseases (fever) raise BMR.

Climate: BMR is lower in warmer climates and higher in cooler climates.

Physiological status: BMR is higher during pregnancy and lactation

Hormones: Thyroxine is the most important in this regard. Hypothroidism lowers BMR whereas hyperthyroidism increases it. Adrenaline increases BMR.

Resting metabolic rate

Resting metabolic rate is whole-body mammal metabolism during a time period of strict and steady resting conditions that are defined by a combination of assumptions of physiological homeostasis and biological equilibrium.

RMR differs from basal metabolic rate (BMR) because BMR measurements must meet total physiological equilibrium whereas RMR conditions of measurement can be altered and defined by the contextual limitations. Therefore, BMR is measured in the elusive "perfect" steady state, whereas RMR measurement is more accessible and thus, represents most, if not all measurements or estimates of daily energy expenditure.

Indirect calorimetry is the study or clinical use of the relationship between respirometry and bioenergetics, where the measurement of the rates of oxygen consumption, sometimes carbon dioxide production, and less often urea production is transformed to rates of energy expenditure, expressed as the ratio between

i) energy and

ii) the time frame of the measurement.

For example, following analysis of oxygen consumption of a human subject, if 5.5 kilocalories of energy were estimated during a 5-minute measurement from a rested individual, then the resting metabolic rate equals = 1.1 kcal/min rate.

A comprehensive treatment of confounding factors on BMR measurements is demonstrated as early as 1922 in Massachusetts by Engineering Professor Frank B Sanborn, wherein descriptions of the effects of food, posture, sleep, muscular activity, and emotion provide criteria for separating BMR from RMR.

Use

RMR measurements are recommended when estimating total daily energy expenditure (TEE). Since BMR measures are restricted to the narrow time frame (and strict conditions) upon waking, the looser-conditions RMR measure is more typically conducted. In the review organized by the USDA, most publications documented specific conditions of resting measurements, including time from latest food intake or physical activities; this comprehensive review estimated RMR is 10 – 20% higher than BMR due to thermic effect of feeding and residual burn from activities that occur throughout the day.

Clinical guidelines for conditions of resting measurements

The Academy of Nutrition and Dietetics (AND) provides clinical guidance for preparing a subject for RMR measures, in order to mitigate possible confounding factors from feeding, stressful physical activities, or exposure to stimulants such as caffeine or nicotine:Further, the correct use of a well-maintained indirect calorimeter includes achieving a natural and steady breathing pattern in order to reveal oxygen consumption and carbon dioxide production rates under a reproducible resting condition. Indirect calorimetry is considered the gold-standard method to measure RMR. Indirect calorimeters are usually found in laboratory and clinical settings, but technological advancements are bringing RMR measurement to free-living conditions

PHYSICAL ACTIVITY LEVEL

The average PAL of healthy, well-nourished adults is a major determinant of their total energy requirement. As growth does not contribute to energy needs in adulthood, PAL can be measured or estimated from the average 24-hour TEE and BMR (i.e. PAL = TEE/BMR). Multiplying the PAL by the BMR gives the actual energy requirements. For example, a male with a PAL of 1.75 and a mean BMR of 7.10 MJ/day (1 697 kcal/day) would have a mean energy requirement of 1.75 × 7.10 = 12.42 MJ/day (2 970 kcal/day).[4] Other examples of these calculations are shown at the bottom of each panel in Table 5.1.

PAL has been calculated in several studies from measurements of TEE and measurements or estimates of BMR. Most of the existing data on the TEE of adults are from studies in industrialized societies, although some investigations have been done in developing countries where many people have lifestyles associated with levels of physical activity that differ from those in industrialized countries (Coward, 1998). A meta-analysis of studies that involved a total of 411 men and women from 18 to 64 years of age showed a modal value for PAL of 1.60 (range 1.55 to 1.65) for both men and women (Black et al., 1996). For the most part, subjects were from affluent societies in developed countries. All were healthy, but 13 percent of the women and 9 percent of the men were overweight or obese, with BMI > 30. Typical sub-populations included students, housewives, white-collar or professional workers, and unemployed or retired individuals; only three persons were specifically identified as manual workers. Hence, the authors of the meta-analysis defined the study participants as people with a "predominantly sedentary Western lifestyle". An expert panel of the International Obesity Task Force (IOTF) suggested a somewhat lower PAL range of 1.50 to 1.55 as being representative of sedentary individuals (Erlichman, Kerbey and James, 2001).

The PAL values that can be sustained for a long period of time by free-living adult populations range from about 1.40 to 2.40. This consultation agreed that a desirable PAL includes the regular practice of physical activity at work or in spare time with an intensity and duration that will reduce the risk of becoming overweight and developing a variety of non-communicable chronic diseases usually associated as co-morbidities with obesity. As discussed in section 5.6, this corresponds to PAL values of 1.75 and higher. On the other hand, a minimum "maintenance" energy requirement was not defined, reaffirming the position of the previous expert consultation which stated that "any figure chosen would reflect a value judgement on what levels of activity above the minimum for survival could be appropriately included in the term "maintenance" (WHO, 1985).

Classification of physical activity levels

Energy requirements are highly dependent on habitual physical activity. This consultation classified the intensity of a population's habitual physical activity into three categories, as was done by the 1981 FAO/WHO/UNU expert consultation (WHO, 1985). However, in contrast with the 1981 consultation, a range of PAL values, rather than a mean PAL value, was established for each category. Furthermore, the same PAL values were used to assign men and women to a PAL category, for the reasons discussed in section 5.1.

The categories shown in Table 5.3 represent the different levels of activity associated with a population's lifestyle. These categories indicate the physical activity most often performed by most individuals in the population, over a period of time. Although there is no physiological basis for establishing the duration of that period, it may be defined as one month or longer.

The term "lifestyle" was preferred to "occupational work", as was used in the 1985 report, because there are groups of people with light or sedentary occupations who perform vigorous discretionary activities regularly, and therefore have a lifestyle that falls more appropriately within the "active" or "vigorously active" categories. It should also be borne in mind that some populations undergo cyclic changes in lifestyle, such as those related to the agricultural cycle among traditional rural societies, or those related to the seasons of the year where hot or mild summers alternate with cold winters. Energy requirements of such populations will change with the energy demands of their cyclical lifestyles.

TABLE 5.3

Classification of lifestyles in relation to the intensity of habitual physical activity, or PAL

Category	PAL value
Sedentary or light activity lifestyl	
Active or moderately active lifestyle	1.70-1.99
Vigorous or vigorously active lifestyle	2.00-2.40*

* PAL values > 2.40 are difficult to maintain over a long period of time.

Examples of lifestyles with different levels of energy demands

Sedentary or light activity lifestyles. These people have occupations that do not demand much physical effort, are not required to walk long distances, generally use motor vehicles for transportation, do not exercise or participate in sports regularly, and spend most of their leisure time sitting or standing, with little body displacement (e.g. talking, reading, watching television, listening to the radio, using computers). One example is male office workers in urban areas, who only occasionally engage in physically demanding activities during or outside working hours. Another example are rural women living in villages that have electricity, piped water and nearby paved roads, who spend most of the time selling produce at home or in the marketplace, or doing light household chores and caring for children in or around their houses.

Active or moderately active lifestyles. These people have occupations that are not strenuous in terms of energy demands, but involve more energy expenditure than that described for sedentary lifestyles. Alternatively, they can be people with sedentary occupations who regularly spend a certain amount of time in moderate to vigorous physical activities, during either the obligatory or the discretionary part of their daily routine. For example, the daily performance of one hour (either continuous or in several bouts during the day) of moderate to vigorous exercise, such as jogging/running, cycling, aerobic dancing or various sports activities, can raise a person's average PAL from 1.55 (corresponding to the sedentary category) to 1.75 (the moderately active category). Other examples of moderately active lifestyles are associated with occupations such as masons and construction workers, or rural women in less developed traditional villages who participate in agricultural chores or walk long distances to fetch water and fuelwood.

Vigorous or vigorously active lifestyles. These people engage regularly in strenuous work or in strenuous leisure activities for several hours. Examples are women with non-sedentary occupations who swim or dance an average of two hours each day, or non-mechanized agricultural labourers who work with a machete, hoe or axe for several hours daily and walk long distances over rugged terrains, often carrying heavy loads.

Extremes of low and high PALs. Extremely low levels of energy expenditure allow for survival, but they are not compatible with long-term health, moving around freely, or earning a living. Such levels have been reported, for example, in elderly mental patients (Prentice et al., 1989), adolescents with cerebral palsy or myelodysplasia (Bandini et al., 1991) and resting adults confined to a whole body calorimeter (Ravussin et al., 1991; Schulz et al., 1992). The mean PAL of 1.21, which is similar to the baseline energy need of 1.27 estimated in the 1985 report, is suggested for short-term survival of totally inactive dependent people in conditions of crisis (WHO, 1985). The present consultation felt that such a value is too low and should not be used in emergency relief programmes, as people are not completely inactive in situations of crisis and the various stresses that impinge on them may increase their energy demands. The consultation hence suggests that food supplies to satisfy a PAL of 1.40, which represents the lower limit of the sedentary lifestyle range shown in Table 5.3, would be more appropriate for short-term relief interventions.

At the other end of the scale, studies have shown PAL values as high as 4.5 to 4.7 during three weeks of competitive cycling (Westerterp et al., 1986), or hauling sleds across the Arctic (Stroud, Coward and Sawyer, 1993). However, such levels of energy expenditure are not sustainable in the long term.

PHYSICAL ACTIVITY LEVEL

The physical activity ratio (PAR) values are commonly used to convert subjects' physical activity recalls into estimates of daily energy expenditure (DEE). A PAR is defined as the ratio between energy expenditure corresponding to a sedentary or a physical activity (kJ/min) and basal metabolic rate [(BMR) kJ/min].

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Thermogenesis

The therm, I mean term thermogenesis comes from the Greek word thermos for heat. All metabolic processes produce heat as a thermodynamic inefficiency or byproduct. In general, however, thermogenesis refers to the process of heat generation, in relation to metabolism and the heat expended in direct response to the food you eat. The heat your body burns is measured in calories. The greater the thermogenic effect of your body, the high number of calories you'll expend [R].

Seemingly, thermogenesis is simple. It's the process of heat generation as a result of the metabolic process. But there is more than just one type of thermogenesis.

In general, there are three different classifications of thermogenesis

Diet Induced Thermogenesis (DIT)

Exercise Associated Thermogenesis (EAT)

Non-exercise activity thermogenesis (NEAT)—not including sleeping, eating, or exercise

Diet-Induced Thermogenesis

Some of the calories you eat are used to digest, absorb, metabolize, and store food, while some other calories are burned off as heat. This process is known by several different names including diet induced thermogenesis (DIT), specific dynamic action (SDA), and the thermic effect of food (TEF).

DIT or the thermic effect of food is essentially the energy "cost" it takes to breakdown your food, digest it, and turn it into fuel. While the cumulative effect of the thermic effect of food on total daily expenditure is small, it still contributes to burning more total calories and supporting your weight loss goals.

A general estimate of the thermic effect of food is around 10% of total daily caloric intake, though the effect varies significantly with different types of foods. The energy required to digest each macronutrient or the (TEF) can be expressed as a percentage of the energy provide by each macronutrient

What Is Thermogenesis:

You may have heard the term Thermogenesis thrown around in the gym or in your HIIT class. Personal trainers and coaches love using training terminology, like posterior chain, or the "after-burn effect".

While thermogenesis is also one of those phrases, what exactly is thermogenesis, and how does thermogenesis work? We're going to get into the nitty gritty details, so you know the ins and outs of thermogenics and how thermogenesis and metabolism relate.

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Fat: 9 calories per gram with a TEF of 0–3%.

Carbohydrate: 4 calories per gram with a TEF of 5–10%.

Protein: 4 calories per gram with a TEF of 20–30%.

Thus, if a meal contains 500kcal then the thermic effect of processing that meal is about 50kcal.

Essentially eating healthier foods, will help you burn even more calories by boosting your metabolism. Yet another reason to eat a healthy mix of lean proteins, quality carbohydrates, and healthy fats.

The thermic effect of food is one of the components of metabolism or total daily energy expenditure (TDEE). Daily energy expenditure consists of three components: basal metabolic rate which includes EAT, diet-induced thermogenesis, and the energy cost of physical activity or NEAT [R].

Basal Metabolic Rate

Often used interchangeably with resting metabolic rate, your basal metabolic rate is defined as the minimum number of calories your body burns to exist without any other outside influences. BMR is the amount of energy that is expended at rest in a neutral environment after the digestive system has been inactive for about 12 hours. It is the rate of one's metabolism when waking in the morning after "fasting" during sleep [R].

Resting metabolic rate is defined as the energy required by your body to perform basic functions at rest. Some of these essential functions include basic brain activities, blood circulation, sleep, nutrient absorption, digestion, temperature regulation, and breathing. RMR represents the minimum amount of energy required to keep your body functioning.

BMR does not consider the variable effect of physical activity and accounts for approximately 60% of daily energy expenditure [R].

Exercise Associated Thermogenesis

The third form of thermogenesis comes from physical activity, also known as the thermic effect of physical activity (TEPA). Exercise burns more calories. Burning calories comes from the thermodynamics your body produces from the activity you engage in.

Aerobic metabolism, requires oxygen and uses either fats or carbohydrates to produce energy, required for low-intensity activity. Anaerobic metabolism converts carbohydrates to ATP when energy is required more rapidly.

TEPA includes both exercise and non-exercise activity thermogenesis (NEAT), which could include things like the energy it requires to walk your dog, take the garbage out, or carry the groceries up the stairs.

How To Increase Thermogenesis

1. Thermogenic Supplements

Thermogenics are often associated with dietary supplements, which are used and marketed for increasing thermogenesis, specifically burning more calories at rest, or enhancing the calorie-burning process, which can help you lose weight faster.

Thermogenics can support weight loss goals, and help you optimize your results when taken consistently. There are several thermogenics which have been proven to increase the production of heat and burn more calories at rest such as ginger root, green tea extract, and turmeric.

2. Physical Activity

The thermic effect of exercise or any type of training will ultimately help you burn more calories. However, the best training mode to increase thermogenesis, is resistance training.

The more muscle mass you have, the more calories you burn at rest. Strength training will help build more muscle mass, therefore burning more calories at rest, boosting your metabolic rate, aka increasing your body's thermic effect. Resting muscle tissue burns 6kcal/lb per day at rest, thus the more muscle you have, the more calories you burn.

Post workout your metabolism stays elevated through a process called excess post-exercise oxygen consumption (EPOC). EPOC also known as the after-burn effect, refers to the oxygen and energy (in calories) it takes for your body to repair your muscle tissue during recovery. EPOC can be a major contributor to your total daily caloric expenditure by increasing your body's thermic effect [R]. Prolonged workouts with more intense resistance training at heavier weights have been associated with a more substantial EPOC [R].

3. Thermogenic Foods

Certain types of foods have a more significant effect on thermogenesis and metabolism than others. Protein for example has a thermic effect ranging between 20-30%, meaning that 20-30% of the protein you eat, is used as energy to process and metabolize. Compare that with 0-3% for fat, which has little to no effect on thermogenesis.

A mixed diet including healthy fats, lean proteins, and quality carbohydrates will result in 5-15% of total daily energy expenditure through diet induced thermogenesis. Although DIT is the smallest contributing component to daily expenditure, including thermogenic foods in your diet does play a critical role in maintaining weight and contributing to weight loss.

4. Non Exercise Activity Thermogenesis

Non-energy exercise activity thermogenesis (NEAT) is the energy expended conducting normal day activities other than planned exercise and training, or (sleeping, eating, and breathing). NEAT includes activities such as walking, cooking, cleaning, yardwork, and involuntary movements like fidgeting.

While it may seem small, even trivial movements and activities substantially increase metabolic rate and the calorie burning process and attribute to the cumulative effect of NEAT. A cohort study published in the American Journal Of Preventative Medicine, followed 12,778 women for 12 years to investigate the effects of fidgeting and sedentary time on mortality rates.

What Is Thermogenesis: Takeaway

Simply put, by increasing thermogenesis, you are in fact increasing your metabolism and its rate, thereby helping your body burn more calories. If your goal is to maintain your weight, lose body fat, or lose a few pounds, increasing your daily energy expenditure is key. While diet and exercise is the tried and true method of reaching your health and fitness goals, including more lean protein, a proven thermogenic supplement, and lifting weights, will induce a greater thermic response and help you burn more calories.

measure energy expenditure.

Total energy expenditure per unit time is called the metabolic rate. It can be measured directly or indirectly as in the case of calorific value of foods. In the direct method for the measurement of energy expenditure for individuals, the Atwater calorimeter is used which consists of a chamber in which a person could live and work for several days allowing at the same time the measurement of his total output of heat.

The energy expenditure thus measured can be related to net energy intake which is the energy in food, minus the energy lost in urine and faeces. Atwater's experiments, measuring energy intake and energy output, lasted a number of days and he was able to demonstrate consistently a fair amount of agreement between the input and the output.

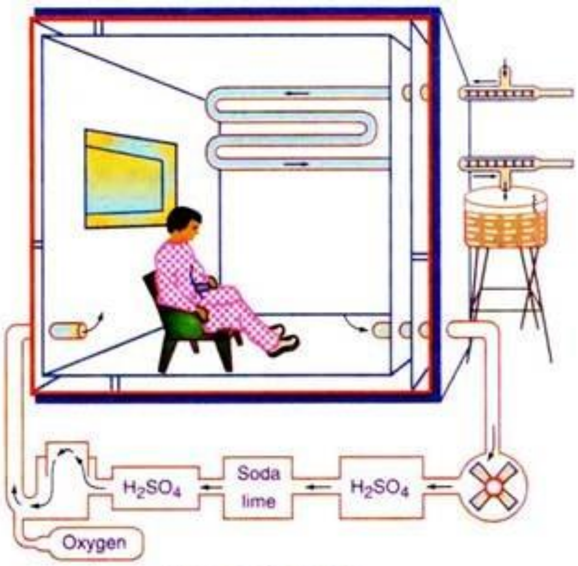
Although nobody uses the human calorimeter these days on account of the difficulties of technique, Atwater's experiment was the first of its kind which demonstrated that the human body behaved like any engine running on combustion of fuels, thus taking the wind out of the sails of the theory of living matter possessing vital spirits.

-ment of energy expenditure in individuals commonly used are:

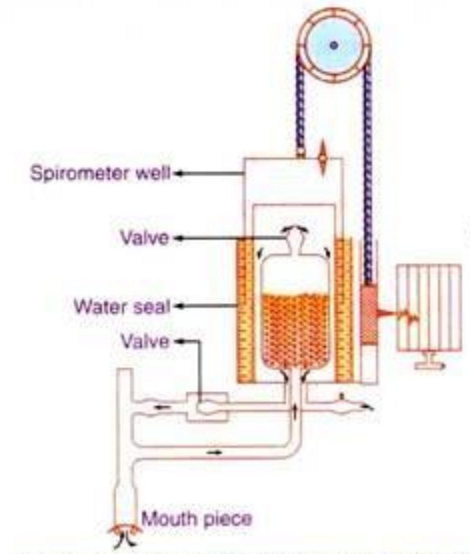
1. The Benedict-Roth Spirometer Method:

This is a closed-circuit breathing apparatus which is filled with oxygen and has a capacity of about 6 litres. Oxygen is contained in a metal drum which floats on a water seal. The person whose O_2 consumption is to be measured breathes in oxygen through an in-spiratory valve and breathes out into the drum through an expiratory valve and a soda-lime canister, so that the CO_2 produced is absorbed.

As the O_2 is used up, the drum sinks and its movement is recorded on a moving paper mounted on a kymograph; from this, the rate of oxygen consumption can be read. The apparatus is accurate and simple to use. It has the disadvantage that it can be used only when the person is at rest or doing very light exercise.



Human calorimeter



Schematic diagram of Benedict-Roth spirometer used for measuring oxygen consumption

2. Douglas Bag Method:

This is a canvas or plastic bag with a variable capacity, usually 100, 200 or 300 litres. The subject breathes through a mouth piece which contains inspiratory and expiratory valves. Room air is breathed in, but breathing out is into the Douglas bag so that all the expired air is collected in it.

The bag is then emptied through a gas meter and a sample of the expired air is taken for analysis of O2 and CO2 content from which the rates of oxygen utilization and CO2 production can be calculated. This method has the advantage that both O2 consumption and CO2 production can be measured at varying grades of activity or muscular exercise.

Person breathing out into the Douglas bag

Respiratory Quotient:

The respiratory quotient (RQ) measures the ratio of the volume of carbon dioxide (Vc) produced by an individual to the volume of oxygen consumed (Vo).

This is represented by the following equation:

RQ = Vc/Vo

This quotient is useful because the volumes of CO_2 and O_2 produced depend on which fuel source is being metabolized. Measuring RQ is a convenient way to gain information about the source of energy which a person is using.

We can then compare the metabolism of a person under different environmental conditions by simply comparing RQ for various foods.

Carbohydrate = 1.00

Fat = 0.70

Protein = 0.81

Mixed diet = 0.85

Factors that increase RQ:

1. Hyperventilation

2. Metabolic acidosis leading to increase in carbon dioxide

3.Overfeeding leading to lipogenesis

4. Exercise

Factors that decrease RQ:

1. Hypoventilation

2. Mild starvation with ketosis

3. Diabetes with ketoacidosis or high rates of urinary glucose loss

4. Gluconeogenesis

5. Hypothermia via continued gluconeogenesis.

Energy requirement is the amount of food energy needed to balance energy expenditure in order to maintain body size, body composition and a level of necessary and desirable physical activity consistent with long-term good health.