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INFLUENCE OF AGE AND BODY WEIGHT ON ENERGY EXPENDITURE OF WOMEN DURING CONTROLLED PHYSICAL ACTIVITY

by

Florence Langford

A Dissertation Submitted to the
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INTRODUCTION

> . . . However important the requirements for specific nutrients may be, the energy requirement is primary and, under ordinary conditions, will be satisfied before, and even at the expense of, any other. Even if the studies already made were sufficient to settle the problems of the past, every new industry, improvement in housing, and changing habits of spending leisure, give rise to new problems . . . . (Orr and Leitch, 1938, p. 509)

Fundamental studies of energy metabolism were conducted during the early part of the twentieth century. These studies provided concepts which are basic to our interpretation of the energy needs of people. Changes in dietary habits of individuals, in housing, in mode of living, and in the nature of occupational and recreational activities necessitate a reevaluation of the energy requirements of people.

Swanson _et_ _al_. (1955) have reported evidence that the Calorie value of diets of women of the North Central Region in the United States was less than the daily energy allowances recommended by the Food and Nutrition Board of the National Research Council (1953, 1958) although there was a relatively high incidence of overweight or obesity among the women. The daily energy allowances recommended by the Food and Nutrition Board for men and women are adjusted in accordance with variations in age, body size, and climate. Although the influence of these factors on basal metabolism have been studied extensively, relatively little investigation has been made of them in relation to energy expenditure other than in the basal state. Maynard (1953) has directed attention to the difficulty encountered in making precise statements about energy requirements because of the variability of energy expenditures during activity and to the need for more information about energy expenditures.

The objective of the present study was to investigate the influence of age and of body weight on oxygen consumption and indirectly, on energy expenditure of women under basal conditions and during controlled physical activity.

REVIEW OF LITERATURE

Man's need for food and his capacity for physical work have been of interest and concern to people for many years. Evidence of this interest and concern is recorded in the scientific literature. According to Lusk (1933, p. 10), the earliest report in the literature on what might be called a respiration experiment is credited to Erasistratus (310-350 B.C.), who "put fowls in a jar and then weighed them and their excreta both before and after food."

Present-day studies of energy metabolism are based upon knowledge accumulated during the past 70 or more years. This body of knowledge includes:

> . . . development of methods and apparatus for the direct and indirect measurement of energy exchange and heat production; applicability of the laws of thermodynamics to biological systems; determination of the energy value of foodstuffs, and their efficiency of utilization in a thermodynamic sense (the specific dynamic action or S.D.A.); discovery of mechanisms of temperature regulation; variability of heat production, especially of the "basal metabolism," in response to every known type of environmental and physiological change; physiology of muscular exercise, including measurement of its efficiency; foundations of the physiological chemistry of energy metabolism; and finally, beginning knowledge of the physiology of energy storage as it occurs in young, growing animals or in the adult during the accumulation of protein, carbohydrate, and fat. (Brobeck, 1948, p. 315).

The history of the development of the science of energy metabolism has been reviewed by various authors (Lusk, 1921; Mendel, 1923; DuBois, 1936; McCollum *et al.*, 1939; McCollum, 1957; Sherman, 1943, 1952; Brody, 1945; Carpenter, 1949; Swift and French, 1954; and Taylor _et_ _al_., 1956).

Basal Metabolism

Factors which influence energy expenditure in the basal state were studied extensively in the early part of the century. These studies were summarized and evaluated by DuBois (1936); his classic monograph provides the source for many of our present-day concepts about basal metabolism. The development of the knowledge of nutrition, particularly in the area of body composition, has, however, stimulated a re-evaluation of these concepts in the light of present knowledge.

The earliest comprehensive study of changes in basal metabolism throughout the life cycle from childhood to old age was that of Magnus-Levy and Falk (1899). These investigators observed that basal metabolism was low in infancy, high in childhood, relatively constant during adult life and decreased with advancing age. Since this study, various investigators including Benjamin and Weech (1943) and Lewis and co-workers (1943a, 1943b) have contributed to our understanding of the changes in basal metabolism with age from birth to maturity.

There have been relatively few studies of the influence of increasing age during adulthood on basal metabolism. Magnus-Levy (1942) compared his own basal metabolism before and after an interval of 50 years. The data indicated that there had been a decrease of 24 per cent in the utilization of oxygen in this period. This corresponded to a decrease of 22 per cent in Calories per hour. Observations of the basal metabolism of five "professors" were also reported. These individuals had a lower energy expenditure than at an earlier age.

Christensen (1949) compiled values for basal metabolism from 16 studies which were reported in the period between 1916 and 1945 in an attempt to evaluate the influence of age on basal energy expenditure. The total number of subjects observed was 761; there were 358 males and 403 females. There appeared to be a trend toward the reduction of basal metabolism with advancing age. Christensen reported also the basal metabolism of 47 women whose ages ranged from 32 to 76 years. These data did not appear to indicate a change in basal metabolism with age. When, however, the data obtained by Christensen were combined with data for other women of the same geographical area, it was found that the basal oxygen consumption, expressed as Calories per square meter per hour, decreased with each decade from 30 to 59 years. An increase in oxygen consumption for women in the seventh decade was followed by a decrease in the next decade. A total of 620 women were included in this series (Leverton et al., 1957).

Shock and Yiengst (1955) reported basal respiratory measurements and metabolism on 152 men ranging in age from 41 to 90 years. Values for these subjects were grouped with those reported in the literature for men of comparable age. There was a linear regression of basal heat production of males on age; the predicting equation was

$$\text{Cal./sq.m./hr.} = 40.22 - 0.110 \text{ age (yrs.)}.$$

In contrast, no evidence of a decrease in basal metabolism with advancing age was found in a study of 17 men and 17 women ranging in age from 60 to 83 years by Miller *et al.* (1957). In this study the Benedict-Roth apparatus and the DuBois chart for estimating body surface in square meters were used.

The interpretation of data from studies of energy expenditure may vary with the unit of expression which is used. Energy expenditure of an individual, expressed as Calories per hour or 24 hours, represents a summation of the influences of different characteristics of the individual on the total heat production. Early investigators in energy metabolism recognized that muscle tissue had a higher metabolic activity than did fatty tissue which until recently was considered to be inert. The apparent dependency of heat production upon surface area was investigated by Rubner (1883) who formulated the *Law of Surface Area*, *i.e.*, that the heat value of the metabolism of a resting individual is proportional to the area of his body surface.

Estimations of surface area have been limited by the lack of a suitable method. Meeh (1879) expressed the surface of animals as

$$S = K \cdot W^{2/3} .$$

S represented surface area in decimeters and W was the body weight in kilograms. DuBois and DuBois (1916) developed a formula for surface area of humans,

$$S = 71.84W^{0.425} L^{0.725} ,$$

where S is the surface area in centimeters, W is the body weight in kilograms and L is the body length in centimeters. The formula was based on careful measurements of the surface area of a few men and women. The formula of DuBois and DuBois, or modifications of the formula, have been used during the past half century for estimations of surface area of persons of various ages. Various formulae and nomograms have been developed for predicting basal metabolism per unit of surface area or as a function of height and of weight of so-called normal individuals (Aub and DuBois, 1917; Harris and Benedict, 1919; Dreyer, 1920; Krogh, 1923; Boothby et al., 1936; and Robertson and Reid, 1952).

From studies at the Carnegie Nutrition Laboratory of the metabolic rates of animals, Benedict (1938) concluded that basal metabolism was not related to body surface area but was influenced by several independent factors including age, weight, height, sex, the amount of active protoplasmic tissue in the body and the internal stimulus to cellular activity.

Variations in the stimulus to cellular activity were attributed to age, sleep, prolonged fasting, character of the diet and the after-effects of severe muscular work. Davenport (1923), in his study of the hereditary factors of body build, suggested the possibility of internal biochemical differences due perhaps to hereditary factors working through special organs that influence metabolism, notably the endocrine glands.

Brody (1945, p. 383) investigated the basal metabolism of animals of different species and concluded that basal energy metabolism did not vary with the first power of body weight, with $W^{2/3}$, or with anatomic surface area; it varied directly with "metabolically effective body weight." If the metabolically effective body weight was designated as W^b, the value of the exponent b was 0.73 for many animals "ranging from mice to cattle, and perhaps elephants" including man. According to Brody, the basal metabolism, in Calories per hour, could be expressed as 70.5 times the body weight in kilograms raised to the 0.734 power.

Kleiber (1947) in a comprehensive review of the relation of body size to metabolic rate, stated that the metabolic rate of homeotherms was correlated positively with body size; this correlation was high when the metabolism was measured under standard conditions. According to Kleiber, the metabolic rate divided by the three-fourths power of body weight was independent of body size and the body weight in kilograms raised to the three-fourths power expressed the metabolic size of an animal in kilograms. Von Schelling (1954) has presented mathematical deductions to support the validity of the 0.73 power of weight as a unit of expression relating metabolism to body size. His work indicated that there was a surprisingly narrow range for the exponent of weight for homeotherms and that the exponent was less than 0.74 and greater than 0.72. The use of the unit of metabolic body size, whether 0.73 power of weight or 0.75 power of weight, has been of value, particularly in comparative physiology.

Development of methods for indirect estimation of lean body mass (Spector, 1956) may mean that in future studies metabolic rate may be expressed in terms of active protoplasmic tissue. Within the immediate future, however, the direct benefit of such techniques may be to test the validity of commonly used expressions. As an example, Johnston and Bernstein (1955) used the nomogram of Boothby _et al_. (1936) for estimation of the surface area of 17 women. Lean body mass, that is, the difference between total body weight and fat mass, was estimated from the total body water of the women. The lean body mass was highly correlated with surface area. The relationship of cell mass to surface area also was highly significant. The basal oxygen consumption of the women was highly correlated with surface area, lean body mass and with cell mass ($\underline{r}$ equalled 0.91, 0.94 and 0.92, respectively).

The influence of body weight on metabolic rate in the basal state is dependent upon the character of the components which comprise the total body mass. Johnston and Bernstein (1955) investigated the oxygen consumption of overweight and underweight women as well as "normal" women. The subjects varied in age from 21 to 59 years and ranged from 60.0 to 284.0 per cent of standard body weight. Basal oxygen consumption ranged from 140 to 357 milliliters per minute or from 85 to 136 milliliters per square meter per minute. These workers estimated that the percentage of body fat which corresponded to 100 per cent standard weight was 36 per cent. "Obesity tissue" was estimated to contain 24 per cent cell mass, six per cent extracellular fluid and 67+ per cent fat. The increase in cell mass with increase in obesity tissue contributed to an increase in oxygen consumption among the overweight women. According to Keys and Brožek (1953), the intensity of basal metabolism per unit mass of nonfat tissue in the body is not reduced with increasing obesity.

From the time of Magnus-Levy and Falk (1899) it has been accepted that the metabolism of women is somewhat lower than that of men. Benedict and Emmes (1915) and Gephart and DuBois (1916) found that values for women were from five to seven per cent less than for men. Benedict (1928) reported that the basal metabolism for males exceeded that for females by 12 per cent. Kisé and Ochi (1934) observed that the differences in basal heat production between sexes became smaller with increase in age. At present, it is uncertain whether the differences in basal metabolism which have been observed between men and women reflect only differences in body composition or whether some additional factor may be operative. DuBois (1936) suggested that the lower metabolism of women was perhaps due to a sex difference in the endocrine system. Keys and Brožek (1953) however have interpreted data from the literature and from their own studies to indicate that the basal metabolism per unit of fat-free body weight may be similar for women and men.

The relative constancy of the basal metabolism of an individual from day to day under uniform environmental conditions has been recognized for many years (DuBois, 1936); this constancy may be attributed to various homeostatic mechanisms (Cannon, 1929). Changes in environmental factors may, however, result in alterations in basal metabolism. Rogers (1939) reported that college students had a less uniform basal metabolism than a group of non-students and attributed the difference to the more settled manner of living of the non-student group.

Effect of environmental temperature on metabolism has long been recognized, and it has become standard practice to maintain room temperature in a zone of thermal neutrality during the administration of basal metabolism tests.

Apparently, climate influences metabolism more than altitude. Reports of carefully conducted studies indicate altitude has little, if any, influence on the basal metabolic rate (Iliff _et_ _al_., 1940; Lewis _et_ _al_., 1943c, 1943d). Observations of basal metabolism that are somewhat lower than the so-called normal have been reported from studies conducted in the southern and southwestern parts of the United States (Tilt and Waters, 1935; Naldandov _et_ _al_., 1938; Thompson _et_ _al_., 1948; and Thompson, _et_ _al_., 1959). Reports indicate that individuals living in tropical areas have lower metabolic rates, based on body size, than individuals living in the temperate zone (Mason, 1940; and Galvão, 1948).

According to DuBois (1936), there appeared to be distinct racial influences on basal metabolism apart from the effect of climate, although no satisfactory explanation was available to account for the racial differences. Quiring (1951) reported that racial differences had little, if any, effect on basal metabolism. It is plausible that some studies of the influence of basal metabolism attributed to race have been confounded by climatic and dietary factors.

The relative constancy of the basal metabolic rate of an adult does not appear to be changed by altering the diet from day to day. However, low basal metabolic rates have been observed in individuals who has subsisted on a low-protein, vegetarian diet over a long period of time (Wakeham and Hansen, 1932). Semi-starvation also has been observed to cause a decrease in the basal metabolism (Keys _et al._, 1950). Thus the plane of nutrition may affect the basal heat production over time although daily variations in dietary intake for short periods of time are not reflected in changes in basal metabolism.

The heat production of an individual whose body temperature is more than or less than his customary body temperature is not considered a true measure of the basal metabolism of that individual as the term is customarily defined. DuBois (1936) found from a summary of studies of basal metabolism of subjects with fever that there was a rise in heat production equivalent to about 7.2 per cent for each Fahrenheit degree rise in body temperature.

The average decrease in metabolism during sleep has been reported to amount to about 10 per cent (Benedict and Carpenter, 1910; Benedict, 1924; Kleitman, 1929; and Mason and Benedict, 1934). Although Grollman (1930) found no difference in oxygen consumption for individuals asleep and lying awake, he observed that oxygen consumption decreased gradually to a minimum about six hours after the onset of sleep and this minimum was about 10 per cent below the basal rate. Passmore and Durnin (1955) concluded that metabolism during sleep was not appreciably less than basal metabolism due to the effect of the last meal prior to the beginning of a night's sleep and to variation in the depth of sleep and in bodily movement throughout the night.

Athletic training appears to have no effect on metabolism in the basal state although higher values have been obtained in basal metabolism studies of active, muscular individuals than have been observed for poorly nourished, relatively inactive individuals (DuBois, 1936). This difference has been attributed to the relative differences in the amounts of muscle tissue present.

Reports on the effect of menstruation on basal metabolism have indicated a wide variation in patterns of individuals during the menstrual cycle (DuBois, 1936). Generally, basal metabolism is considered to reach its maximum one to two days before the menstrual flow, is lowest during the menstrual period, after which it tends to rise slowly with some indication of another rise mid-way of the inter-menstrual period. Since there is a possibility of a cyclic pattern with menstruation, it has been customary to measure basal metabolism on women at a time other than during the menstrual period.

Energy Expenditure During Activity

Both direct and indirect calorimetry have been used in the investigation of energy expenditure during activity as well as in the basal state. Particularly for studies of the metabolic cost of activity, however, methods of indirect calorimetry have been advantageous and have permitted observations of types of activity which would not have been feasible in a room calorimeter. The principles of direct and indirect calorimetry have been reviewed by Swift and French (1954).

In the initial respiration studies, measurements of energy expenditure under conditions involving different amounts and kinds of physical activity were hampered by the weight and bulk of the equipment that was used. The development of a small, light-weight, portable respirometer or dry gas meter reported by Kofrányi and Michaelis (1940) expedited investigations of energy expenditure under a wide variety of conditions. This respirometer, weighing about 4 kilograms and of a size that could easily be carried on the back of a subject, measured the total volume of expired air while it simultaneously diverted a representative portion into a small rubber collection bag for analysis.

The details of construction and operation of the Kofrányi-Michaelis respirometer and its use as a new technique in indirect calorimetry have been reviewed and evaluated (Müller and Franz, 1952; Insull, 1954; and Durnin and Brockway, 1959). This respirometer has been compared with the Douglas bag as a means for determining energy expenditures during a variety of simple activities (Orsini and Passmore, 1951; and Passmore *et al.*, 1952). It was found that in most cases the difference between the amount of oxygen consumed as measured by the respirometer and the Douglas bag was less than 0.10 cubic centimeter, with the difference expressed in terms of energy production being negligible.

The extensive literature on investigations of energy expenditure during activity has been reviewed by Passmore and Durnin (1955) along with a critical analysis of the factors which influence the metabolic cost of activity.

Similar parameters have been used to express the metabolic cost of activity as have been used for basal metabolism. As mentioned above, interpretation of data from studies of energy expenditure may vary with the unit of expression which is used. Energy expenditure measurements have been presented in diverse ways in the literature, thus the results of different authors are difficult to compare. Gross Calories and Net Calories have been used to express the metabolic cost of an activity. Net Calories have been changed from Gross Calories with corrections for basal metabolism and/or specific dynamic action. Energy expenditures have been expressed as Calories per hour, per 10 minutes, per minute, per square meter of body surface area, per kilogram of body weight, per gross body weight, and per fat-free body weight. Much calculation must be done before such data can be compared. Durnin (1959), in reporting his study on use of surface area and body weight as reference standards, has called attention to the need of a uniform manner for expressing results of measurements of energy expenditure. He studied results of energy expenditure measurements of about 160 subjects, using graphs and a multiple regression analysis, and concluded that surface area was no more useful as a standard than gross body weight. Because weight can be easily and accurately measured whereas surface area is a calculated not a measured unit, he advocated expressing energy expenditure as gross Calories per minute per gross body weight, or as gross Calories per minute with the weight of the subject also given.

Although the influence of such factors as age, body size, sex, and race on basal metabolism has been studied by various workers, there have been relatively few studies of the influence of these factors on energy expenditure during physical activity. In a study of the energy expenditure of a group of middle-aged housewives and their adult daughters (Durnin et al., 1957), a decrease in energy expenditure with age was observed. These workers considered a decrement of three per cent per decade to be in keeping with their results. Mahadeva et al. (1953) reported the energy expenditures of 50 subjects, 35 men (26 European and nine Asiatic) and 15 women (all Europen), during walking and stepping tests and concluded that the factors of age, height, race, sex, and resting metabolism had little influence on energy expenditures. Their results were interpreted to indicate that in physical activity involving the movement of body weight the energy expenditure cost was directly proportional to body weight.

The data presented by Mahadeva et al. (1953) do not appear adequate to indicate that only body weight, and not age, had any influence on the energy expenditure of women. The range of weight of the women studied was 56 to 79 kilograms, and the mean weight was 65.7 kilograms. The age range was 14 to 53 years with a mean age of 26.6 years. The distribution of the ages by decades was as follows: second decade, four subjects; third decade, seven subjects; fourth decade, two subjects; fifth decade, one subject; and sixth decade, one subject. The relatively limited number of subjects distributed over a wide range of age would appear inadequate to segregate the effect of age, if any, from other characteristics of the subjects.

Attention has been given to different factors which might contribute to variability in results of studies of energy expenditure. Erickson and co-workers (1946) investigated the possibility that repeated performances might result in a reduction in the metabolic cost of walking on a treadmill under standardized conditions; however, no influence of training was apparent. The physical fitness of the subjects has been found to influence the results obtained with both men and women (Methany et al., 1942).

The possible influence of the food taken before a physical activity test has been studied (Orr and Kinloch, 1921; Mahadeva et al., 1953; and Durnin and Weir, 1954). Mahadeva and his associates reported that the specific dynamic action of food amounted to two Calories per 10 minutes at the most, and the coefficient of variation observed during exercise was less than that observed under basal conditions. Durnin and Weir studied the variation in the metabolic costs of five activities carried out at five different times on five consecutive days. They found differences between subjects and between activities to be highly significant, with no significant differences between different times of the day or between days. Since the variation within the five activities increased with the metabolic rate, the authors expressed the data logarithmically and found that the differences between times of the day then were significant.

Robinson (1942) compared the energy exchange of a large man with that of a small man both exercising to exhaustion on the treadmill under conditions of high temperature and humidity; it was concluded that the factors studied did not affect the efficiency in performing the work but did affect the comfort of the subjects. The small man was able to maintain heat balance; the large man was not able to dissipate all of his body heat.

Energy expenditure during walking

The rate of walking has been observed to have a direct effect on energy expenditure. Data reported for horizontal movement at varying speeds, from one mile per hour to 10 miles per hour, in studies conducted in laboratories in five different countries have been summarized (Passmore and Durnin, 1955) and the energy expenditure observed was linearly proportional to speed over the range of approximately two to four miles per hour with the expenditure increasing at faster rates at the higher speeds. The weights of the subjects in these studies were between 60 and 76 kilograms. Walking at a slow rate, *i.e.*, at approximately one mile per hour, has been reported (Smith and Doolittle, 1925; Benedict and Parmeter, 1928) to be tiring and boresome to the subject and uneconomical with respect to energy expenditure; energy expended for work accomplished was higher than that expended during walking at twice the speed.

As mentioned above, Mahadeva *et al*. (1953) investigated energy expenditure during walking. His subjects walked on a level indoor track at a constant speed of three miles per hour; energy expenditure was found to be proportional to body weight. The calculated energy expenditure during walking ranged from 251 to 268 Calories per hour.

Many measurements have been made of grade walking, both outdoors and on a treadmill. The outdoor studies, for the most part, were done either at high altitudes or with the heavy, clumsy Zuntz apparatus (Passmore and Durnin, 1955). The inclinations used in one series of studies of grade walking were zero, five, 10, 15, and 25 per cent (Margaria, 1938).

Keys et al. (1950) observed energy expenditures of 16 healthy male subjects, average weight, 70.6 kilograms, walking at 5.6 kilometers per hour up a 10 per cent incline to be 534 Calories per hour, a figure that compared favorably with the findings of Margaria (1938).

Individual variations in the response of subjects to standardized activity tests with the treadmill have been observed and reported (Ferres et al., 1954), and emphasis has been given to the importance of giving attention to these variations.

Mean values for subjects walking on a horizontal plane at a rate of one mile per hour have ranged from 78 Calories per hour (Swartz, 1929) to 108 Calories per hour (Orsini and Passmore, 1951). Smith and Doolittle (1925) reported a mean value of 109 Calories per hour for walking at two miles per hour. This was nearly identical to the value of 108 Calories per hour reported by Erickson et al. (1946). Other mean values of subjects walking on the horizontal at this speed included 211 Calories per hour (Douglas and Haldane, 1912) and 237 Calories per hour (Benedict and Murschhauser, 1915). Mean values for walking on a level at three miles per hour have ranged from 156 Calories per hour (Smith and Doolittle, 1925) to 300 Calories per hour (Douglas and Haldane, 1912).

Stepping tests

Stepping tests of various kinds have been used in studies of energy expenditure as well as for appraising physical fitness. The tests are useful for such purposes because they are simple to administer, and the work load can be controlled with relative ease.

Various modifications of tests based upon stepping have been used in different laboratories. In general, the modifications have been with respect to the length of time of the test and/or the height of the step used so that there has been considerable variation in the work performed by the subjects. Three step heights were studied by Passmore and Thomson (1950), who found that stepping at the rate of 14 to 18 steps per minute on a 10-inch step was representative of the range for optimal efficiency for stepping. In an investigation by Mahadeva _et al_. (1953), subjects stepped onto a 10-inch stool at the rate of 15 steps up and down per minute in cadence with a metronome; energy expenditures ranged from 272 to 289 Cal./hr. Statistical analysis indicated that energy expenditure during stepping was directly proportional to body weight. Ford and Hellerstein (1957) used a two-step platform with 9-inch risers and a test that involved 20 trips over the steps in 90 seconds (the Master two-step test). The oxygen consumption of the subjects was 6.8 times the resting oxygen consumption and the average energy expenditure was approximately 510

Cal./hr.; this test was considered to be "moderately severe exercise."

Several stepping tests have been used for clinical evaluation of physical fitness based upon cardiovascular response to a standard amount of exercise. The effect of varying the height of the step on cardiovascular response was evaluated by Elbel and Green (1946), using seven stepping tests which had been reported in the literature between 1920 and 1944. The step heights studied included a 13-inch block, a 13-inch stool, an 18-inch chair, a 20-inch bench (the widely-used Harvard step test), an 18-inch platform, 12- and 20-inch benches, and a two-step platform with 9-inch risers. Exercise periods of 30 and 60 seconds were used for each step height; the increment in the pulse rate at one minute after exercise was not influenced specifically by the height of the step or by the length of the exercise period. Sloan (1959) reported the use of a modified Harvard step test for women. He found that healthy young women performing the test on a step 17 inches high had fitness indexes comparable to those of healthy young men stepping at the standard height of 20 inches.

METHOD OF PROCEDURE

Experimental Plan

The influence of age and body size on oxygen consumption and indirectly on energy expenditure was investigated for women during controlled physical activity and in the basal condition. Controlled activities were resting, walking on a treadmill at two rates of speed and stepping on a two-step platform.

Thirty-five women participated as subjects in the treadmill series. The women were selected according to age and to body weight. One group, which served as a reference for comparison, consisted of seven women who were in the age range of 25 to 34 years and who were of desirable body weight in relation to height and age. The other subjects were distributed among four groups with seven subjects in each group. Two groups represented variations in age and two groups represented deviations in body weight from the desirable body weight. Five subjects, selected at random, participated in the stepping tests.

The energy value of the diet and the protein and thiamine intakes of the subjects were estimated from two 24-hour diet records obtained by recall at different times during the study. Medical histories were obtained for each subject and anthropometric measurements including skinfold thicknesses were determined.

Subjects

Forty women subjects were selected from volunteers in the community of Ames, Iowa. They were apparently in good health according to physical examination and medical histories. All were active or moderately active; the subjects included graduate students, women engaged in professional work and homemakers. All were on self-selected diets. Nineteen of the women had married and 12 had had children. Each woman was visited before the tests were administered and the plan of procedure was described. Special emphasis was given to the necessity of maintaining her customary routine and food intake pattern during the period of study. None of the subjects had participated in a study of energy expenditure previously.

Thirty-five subjects participated in standardized walking tests. The subjects were selected according to age and body weight and were distributed among five groups with seven subjects in each group. Groups A, B, and C were composed of women who were underweight, of desirable body weight and overweight, respectively. Subjects in Groups A, B, and C were young, adult women within the age range of 25 to 34 years. Subjects in Group A had body weights that were 10 per cent or more below desirable body weights for their ages and heights. The overweight subjects in Group C were 15 per cent or more above desirable body weights for their ages and heights. Subjects in the reference group, Group B, were within +15 to -10 per cent of the body weights considered to be desirable for their heights and ages. Evaluations of desirable body weight were based upon clinical appraisal, anthropometric measurements and standard height-weight-age tables (Metropolitan Life Insurance Company, 1951).

Subjects in Groups B, D and E were all considered to be of desirable body weight in relation to height and age. The women in Group D were within the range of 45 to 54 years of age; women in Group E were in the age range of 65 to 74 years.

Five women participated in a standardized step test. The subjects varied in age from 16 to 43 years and in body weight from 51.1 to 70.0 kilograms.

Basal Metabolism

Oxygen consumption during the basal state was measured in duplicate on two non-consecutive days within a 7-day period. Measurements of basal metabolism were made at a time near the period when the subjects worked on the treadmill but not always within the same week.

The subject was given instructions for the basal metabolism test several days prior to the day of measurement. The subject was asked to eat her usual meal on the night before the test and to consume no food or beverage, other than water, after the meal. She was requested to obtain at least eight hours of sleep or rest in bed and to engage in no physical activity after rising other than the minimum amount required for dressing. The form used for instructions for the basal metabolism test is given in Table 25 (in Appendix).

The subject was brought by automobile to the laboratory as soon as possible after arising. Immediately upon arrival she was asked to lie down and was left alone for 30 to 45 minutes for complete rest in a room that was kept at a comfortable temperature and was free from external disturbance. Many of the subjects slept throughout the rest period. Near the end of the rest period, the oral temperature was measured and the pulse and respiration rates were observed and recorded.

The basal metabolism was measured by two methods. In one procedure the amount of air expired by the subject for two eight-minute periods was measured with a Kofrányi-Michaelis respirometer,[a] and aliquots of the expired air were obtained in a rubber collection bag for analysis of carbon dioxide and oxygen. The aliquot of expired air was sampled continuously throughout the test period and was equivalent to 0.6 per cent of the expired air. At the end of the eight-minute test period, the aliquot of air was transferred immediately to a Baily gas sampling bottle[b] and held over mercury until analysis of the gases was completed.

The second procedure which was used for measurement of

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[a] Des Max Planck-Instituts fur Arbeitsphysiologie, Dortmund, Germany.

[b] A. H. Thomas Co., Philadelphia, Pennsylvania.

basal metabolism was the customary clinical procedure and was carried out with a Benedict-Roth Metabolor.[a] In this procedure, a spirometer was filled partially with oxygen of medical grade. The system was a closed system and the carbon dioxide from the expired air was absorbed by soda lime. The amount of oxygen consumed during a period of six minutes was determined from the height of the spirometer at the beginning and end of the test. The measurement was repeated for a second six-minute test period.

Immediately following the determination of basal metabolism, body weight was determined[b] and stature was measured, with the subject wearing a minimum of clothing and no shoes. No correction was made for the weight of the clothing.

Weight was recorded to 0.01 kilogram. Stature was measured on a platform having a broad, heavy base and a rigid vertical upright to which standard meter sticks were attached. The upright was 72 inches high, and of the same width as the platform. It provided a solid support for the back. The subject was required to stand with the head held comfortably erect, the shoulders, buttocks, and heels touching the upright, and the feet parallel. A hardwood triangle in contact with the upright was brought down to touch the subject's head.

An urine collection was obtained with the subject record-

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[a] Warren E. Collins, Inc., Boston, Massachusetts.

[b] Platform balance, Howe, Rutland, Vermont.

ing the time of voiding urine. This collection was measured, diluted to volume, and an aliquot was frozen and held until analyzed for nitrogen. Data from the urine analysis were used in calculating the non-protein fasting respiratory quotient.

The subject was served breakfast after the period of observations, tests, and measurements. Because the investigator was aware of the importance to the study of obtaining and maintaining the interested cooperation of the volunteer subject, efforts were made to offer the kind of breakfast she would enjoy and to make the breakfast period as pleasant as possible.

Anthropometric Measurements

On one of the two test mornings certain additional physical measurements were made. These additional measurements were 14 in number, as follows: transverse and anterior-posterior diameters of the chest; bi-iliac and bi-trochanter width; upper arm girth, both right and left, at a point midway between the tip of the shoulder and the tip of the elbow; maximum calf girth, both right and left; strength of grip in each hand; and four skinfolds (upper arm, both right and left at a point just below the insertion of the deltoid muscle; chest, right frontal, at a point just below the rib cage; and chest, right dorsal, just below the base of the scapula). These measurements were made with a standard metal caliper,[a] a dynamometer for measuring strength of grip,[b] and a flexible steel tape calibrated in tenths of a centimeter.

Standardized Activities

Walking the treadmill

Walking tests were administered to 35 subjects over a period of 10 months (January through October, 1959). The code numbers assigned to the subjects participating in these tests are presented in Table 1. The tests were given in series to

Table 1. Code numbers of subjects participating in the walking tests

Weight	Age 25-34 years	 45-54 years	 65-74 years
More than 10 per cent below "desirable" weight	Group A Nos. 1-7		
Within +15 to -10 per cent of "desirable" weight	Group B Nos. 1-7	Group D Nos. 1-7	Group E Nos. 1-7
More than 15 per cent above "desirable" weight	Group C Nos. 1-7		

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[a] Calipers for trunk measurements, Czechoslovakia; caliper for skinfold measurements (constant-pressure caliper, 10 gm./mm.^{2}, with circular jaw faces measuring 40 mm.^{2}), Rissoli, Bologna, Italy.

[b] K. W. Sheerer, Germany.

the subjects. One subject from each group participated in each series of tests; there were seven series of tests. The first series of tests was given to subjects 1A, 1B, 1C, 1D, and 1E. The second series was given to subjects 2A through 2E. A similar pattern was followed for the succeeding series of tests, with the last series including subjects 7A through 7E. Insofar as the varied activities and responsibilities of the volunteer subjects would permit, the tests were given at random to the women who participated in any one series.

The walking tests were given in duplicate to each subject on two non-consecutive afternoons. Energy expenditure was measured for the subject in a resting state preceding the period of actual walking. The subject came to the laboratory about one hour after the noon meal. Wearing a minimum of clothing, she rested in bed for approximately 30 to 45 minutes. Oral temperature was measured and pulse and respiration rates were observed and recorded prior to collection of expired air. When the subject appeared to have relaxed completely, expired air volumes were measured for two eight-minute periods, and aliquots were collected for analysis, using the same procedure that was used in the basal metabolism tests. Data from the analyses of these samples were utilized to calculate a base line with which oxygen consumption during walking could be compared.

After her resting tests the subject was weighed with a minimum of clothing, her stature was measured, and a timed urine collection was obtained. This collection and the one collected following the walking tests received the same treatment as the collection made following the basal metabolism tests.

A treadmill[a] adjusted to a four per cent incline, was used for the walking tests. This treadmill was located in a large, light, pleasant, well-ventilated room that could be kept comfortably warm in winter. The room was air-conditioned for summer comfort.

Dressed for indoor activity and for walking comfort, the subject walked on the treadmill for two 15-minute periods while wearing the respirometer on her back. The meter weighed approximately eight pounds. No correction was made for this weight. Differences in energy expended in walking with or without carrying the meter have been found to be insignificant (Insull, 1954). Immediately preceding the walking tests a brief explanation and demonstration of the procedure to be followed was given with the subject participating in the demonstration. On the first test day the first 15-minute walking period was at the rate of two miles per hour; the second 15-minute period, three miles per hour. The order in which these rates for walking was used was reversed on the second test day, with the subject walking first at three miles per hour, then at two

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[a] A. R. Young, Power Transmission Engineers, Indianapolis, Indiana.

miles per hour. During the last five minutes of each 15-minute walking period the volume of expired air was measured and an aliquot was collected for analysis.

Following each 15-minute walking period the subject stepped directly from the moving treadmill to an adjacent platform and seated herself in a comfortable arm chair to rest while the volume of expired air was measured and an aliquot collected over a period of 10 or more minutes as a basis for determination of oxygen debt. During this time pulse rate was observed and recorded at approximately one-minute intervals. The resting-after-walking period was terminated when the pulse rate approached or returned to the previously observed resting pulse rate. There was a 10-minute rest period for the subject between the two walking periods. During this time the subject moved away from the treadmill to another part of the room and sat quietly at rest. Immediately after the second resting-after-walking period an urine collection was obtained.

A plastic and rubber half-mask for the face was used in place of the rubber mouthpiece and nose clamp with a few of the subjects during the walking tests. It was planned to use this mask with most if not all of the subjects. It was not possible to do so because the mask could not be fitted properly to many of them. The dead air space of the half-mask was negligible.

Stepping

Five volunteer subjects, designated as 1S, 2S, 3S, 4S, and 5S in this study, were selected to participate in a stepping test. Their ages ranged from 16 to 43 years; their weights, from 51.1 to 70.0 kilograms; and their heights, from 162.2 to 167.5 centimeters. These weights varied from -10 to +37 per cent of so-called desirable weight, according to the standards used in this study for the evaluation of weight based upon age and body build. The subjects included a high school student, an undergraduate college student, two graduate college students, and a laboratory technician. Two of these subjects, 2S and 3S, reported having gained considerable weight during the past year. One of these two, 2S, was on a self-imposed "reducing" diet; the other one, the only married woman in this group, had a nine-months-old daughter. With the exception of the youngest subject, all had worked in a nutrition laboratory and were familiar with some of the routines involved in various human nutrition research projects. None of the subjects had participated in energy metabolism studies involving the measurement of oxygen consumption during physical activity.

The activities included in the stepping tests were three in number, namely: resting before stepping, stepping, and a recovery period after stepping with return to resting. These tests were administered in an air-conditioned laboratory during the month of August, 1957. The tests were given in duplicate to each subject on two non-consecutive days. One of the subjects, PS, came to the laboratory for her tests in the afternoon; the other four had their tests in the mornings.

Certain preliminary instructions were given to a subject before she reported to the laboratory. Emphasis was given to the importance of maintaining, insofar as was possible, the usual routine of physical activities and the customary food intake pattern. She was asked to come to the laboratory for her tests one hour after breakfast (or luncheon) and to note the time at which the bladder was emptied before arriving for the tests.

Immediately on arrival at the laboratory the body weight of the subject was determined with a minimum of clothing and no shoes and her stature was measured, using the equipment and procedure used with the basal metabolism tests. Following a rest period of 30 to 45 minutes, oral temperature was measured and pulse and respiration rates observed and recorded. The respirometer was shown to the subject and a brief description of the resting measurements to be made with it was given. Using the techniques and methods described earlier, the rubber collection bags were rinsed, and expiratory air for two eight-minute periods was measured, with aliquots being collected for analysis.

Following these observations and measurements, an urine collection was obtained. This collection was measured, diluted to volume, and an aliquot was refrigerated under toluene and analyzed for nitrogen within 24 hours. The same procedure was repeated with an urine collection obtained following the stepping tests.

The procedure used in the stepping tests was explained, and the stepping activity was demonstrated, with the subject participating briefly in the demonstration. In the stepping test the subject stepped up and down, repeatedly, on a two-step platform, stepping to a metronome set at 84 beats per minute. The setting for the metronome was selected after several trials with stepping on the two-step platform and on stair steps in different locations. The hardwood platform, 20 inches high and 36 inches wide, was constructed especially for this activity test and was strong enough to hold at least 90 kilograms of weight. Each tread measured 12 inches in depth and the risers were 10 inches high. These steps were firmly braced. The dimensions for the platform were selected after studying dimensions of platforms used for stepping tests by other investigators (Elbel and Green, 1946; Consolazio *et al.*, 1951; and Mahadeva *et al.*, 1953). A design of the two-step platform is shown in Figure 1.

Wearing the respirometer on her back, the subject stepped for two consecutive four-minute periods with no resting period between the two periods. In order to minimize the movement of the rubber tube carrying the subject's expired air to the

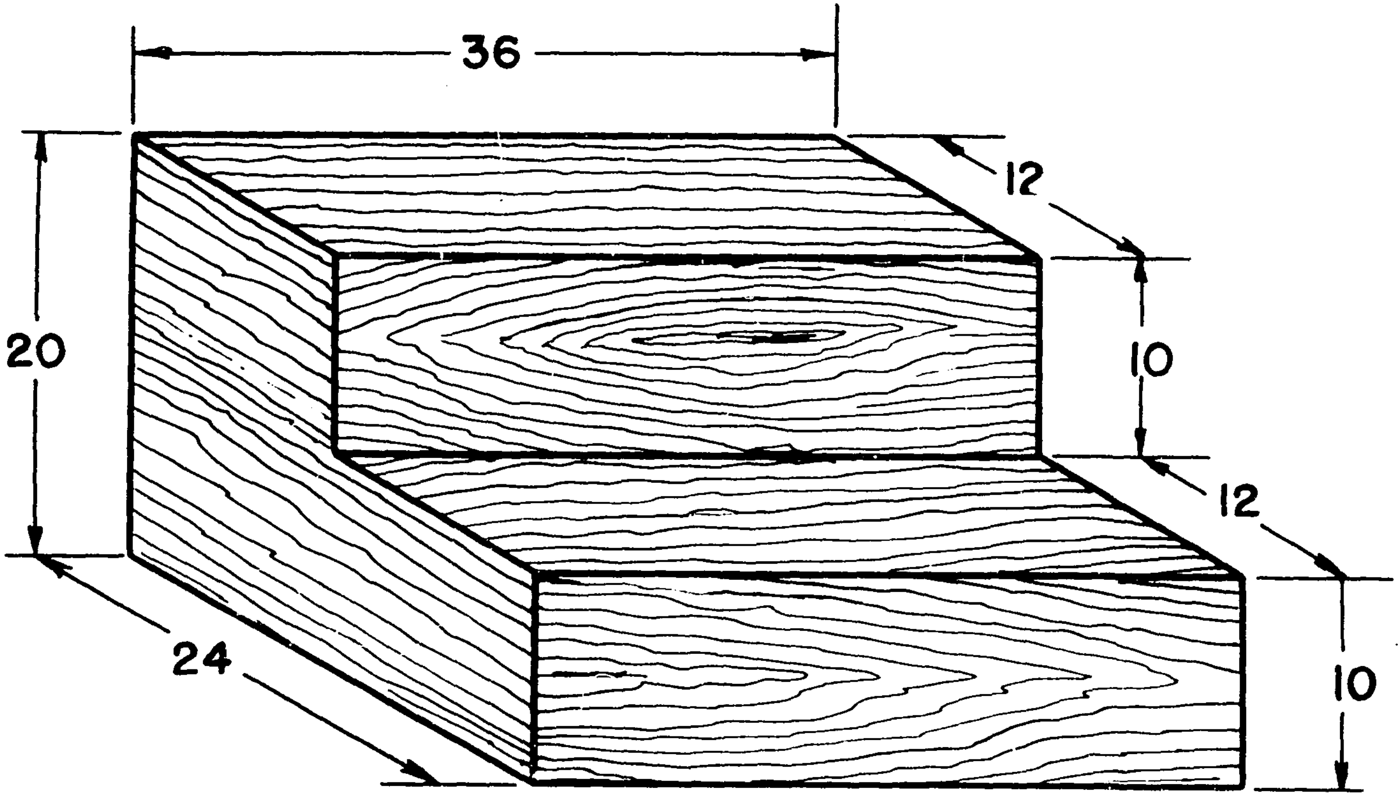

Figure I. Two-step platform used for stepping tests respirometer, a short length of light-weight rubber tubing was used to tie the tube to one of the shoulder straps supporting the instrument. During the stepping periods volumes of expired air were observed and recorded[a] and aliquots were collected for analysis.

After the two four-minute periods of stepping, the subject moved from the two-step platform to the bed as the respirometer was shifted from her shoulders to a small bedside table. During this time expired air volume was measured continuously and an aliquot was collected. This measurement and collection were continued, with the subject resting in bed, until her pulse rate approached or returned to her previously observed resting pulse rate.

Chemical Analyses

Gas analyses

Aliquots of the expired air were transferred to Bailey gas-sampling bottles for storage over mercury until analyzed. The samples were analyzed in duplicate, with these analyses being made for the most part within 24 hours after collection. In a very few cases, due to technical difficulties, analyses were not completed until 30-36 hours after collection. Re-

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[a] Appreciation is expressed to Dr. Pilar Garcia and Marjorie Campbell for assistance with the recording of observations during the stepping tests.

peated analyses of expired air held under the conditions used in this study for various lengths of time indicated that differences among samples held for 24 hours, for 30 hours and for 36 hours were negligible. The expired air collected from the subjects participating in the stepping tests was analyzed for oxygen and carbon dioxide using the Haldane-Henderson method (Peters and Van Slyke, 1932). Aliquots of expired air collected from the subjects given the walking tests were analyzed for carbon dioxide using the Haldane-Henderson method. In analyzing these samples for oxygen two methods of analyses were utilized, namely: the Haldane-Henderson method, and the physical method[a] employing the use of the Beckman Oxygen Analyzer.[b]

Urinary nitrogen

Aliquots of the urine collected at periods corresponding to the measurement of oxygen consumption under basal conditions, at rest and during the activity tests were analyzed[c] for nitrogen by the macro-Kjeldahl method.

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[a] Appreciation is expressed to Duane Hougham for the oxygen analyses made with the Beckman Oxygen Analyzer.

[b] Beckman Oxygen Analyzer, Model B, Beckman Instruments, Inc., Fullerton, California.

[c] Mrs. Lois Burt, Mrs. Rose Mao and Joan Duncan assisted with the urinary nitrogen analyses.

Use and Calibration of the Kofrányi-Michaelis Respirometer

Certain procedures were followed in the use of the Kofrányi-Michaelis respirometer. The respirometer was checked regularly to see that it was functioning properly. This was done by connecting the respirometer to the operator, using a rubber mouthpiece, connection valve, nose clamp, and rubber tube, and observing the movement of the meter for several minutes as expired air passed through the instrument. If there appeared to be an increase in resistance or if the meter was not registering properly, the respirometer was dismantled and the source of trouble located and repaired. Two rubber collection bags were kept with some expired air in them at all times between periods of actual use. Immediately before use, the bags were rinsed three times with portions of the operator's expired air, and these portions were expelled as completely as possible by rolling the bags tightly. The empty bags were connected to a two-way glass stopcock attached to the respirometer. The rubber mouthpieces were soaked in distilled water overnight before each test in order to increase their softness and pliability. These mouthpieces were cleaned after each use with detergent and water; and then by immersing for 10 minutes in a solution of iodine in alcohol. After use, the connection valve was taken apart, washed carefully with hot water and detergent, rinsed, dried, re-assembled, and checked to see that the mica disks were in position for the inlet and outlet valves to function properly.

When measuring the expired air of a subject the rubber mouthpiece, connection valve, and rubber tube were connected, and the subject was asked to insert the rubber mouthpiece in her mouth. After connecting the rubber tube to the respirometer, its position was checked to insure that it was adjusted satisfactorily. The subject was asked to assist in detecting any possible leaks or faulty connections. A clamp was placed on the subject's nose and adjusted. When it was certain that there was no leakage of air, eight liters of expired air were passed through the respirometer and a sample collected in the rubber collection bag for the purpose of rinsing it with the subject's expired air before collecting the sample that was to be analyzed for oxygen and carbon dioxide. The clamp on the bag was closed, and the bag was disconnected from the respirometer and kneaded gently. After rolling the bag tightly to expel the rinsing sample, it was re-attached to the respirometer.

Two respirometers were used to measure volumes and to collect samples of expired air from the subjects during the tests. The metering devices on the respirometers were calibrated against a Tissot spirometer.

The procedure used in calibrating each respirometer was as follows: The Tissot spirometer was filled with room air. The air was metered through the respirometer at different volumes per unit of time selected to correspond to the range of values observed in the tests. Initial and final readings of volumes and temperatures of air in the Tissot and of air metered through the respirometer, and the ambient barometric pressure, provided bases for calculation of correction factors for various rates of gas flow through the respirometer. These correction factors are presented in Table 2.

Table 2. Calibration factors for the Kofrányi-Michaelis respirometers

Respirometer No. 0.986		Respirometer No. 1.000	
Liters per minute	Correction factor	Liters per minute	Correction factor
5.0- 7.9	1.083	5.0- 7.9	1.078
8.0-10.9	1.083	8.0-10.9	1.067
11.0-13.9	1.066	11.0-13.9	1.062
14.0-16.9	1.061	14.0-16.9	1.066
17.0-19.9	1.060	17.0-19.9	1.048
20.0-29.9	1.056	20.0-22.9	1.054
30.0+	1.056	23.0-30.0+	1.068

Calibration of Rubber Collection Bags

Two rubber bags were used for collecting the samples of expired air from the subjects participating in the activity tests. The procedure for the calibration of the change in concentration of oxygen and carbon dioxide of the expired air collected in these bags was similar to that used by Hawthorne *et al*. (1956) and by Kereluk (1956).

A Douglas bag of 150 liters capacity was filled with expired air. The contents were mixed by gently kneading the closed bag. The composition of this air was determined by sampling for analysis directly into Bailey gas-sampling bottles at the beginning and end of the metering periods. Air from the Douglas bag was metered through the Kofrányi-Michaelis respirometer at different volumes per unit of time according to the range of values observed in the tests. Palpitation of the bag by hand was done to simulate the rhythmic pattern of successive expirations. Samples of air were taken from the rubber collection bags and analyzed for oxygen and carbon dioxide. The changes in the concentrations of oxygen and carbon dioxide for the rubber collection bags are given in Table 3.

Calculation of Data

Using the data collected with the Kofrányi-Michaelis respirometer on oxygen uptake and carbon dioxide production and the analyses for urinary nitrogen, heat production was calculated according to the methods of Brody (1945) and Consolazio _et al_. (1951). The factor used for conversion of oxygen uptake to heat production was determined by the experimentally observed non-protein respiratory quotient. All gas volumes were reduced to standard conditions of temperature of zero degrees Centigrade and pressure of 760 millimeters of

Table 3. Calibration factors for concentrations of carbon dioxide and oxygen of expired air in respirometer bags

Rate of flow, liters/min.	Bag No. 1 Carbon dioxide	 Oxygen	Bag No. 2 Carbon dioxide	 Oxygen
	% of original	% of original	% of original	% of original
For 8 min. collection period				
3	84.99	103.78	83.69	103.21
4	87.70	102.75	88.00	102.25
5	91.06	101.23	92.25	101.34
6	90.67	102.20	93.80	100.49
7	91.39	101.10	95.96	100.49
8	95.70	100.65	97.40	100.46
9	99.36	100.22	97.95	100.46
For 5 min. collection period				
12	100.00	100.00	98.00	101.64
18	100.00	100.00	98.16	100.40
20	100.00	100.00	98.39	100.38
22	100.00	100.00	98.94	100.04
30	100.00	100.00	100.00	100.00

mercury, dry.

Measurement of oxygen debt after the walking and stepping tests were made for all subjects. The method used for calculation of oxygen debt was based upon those used by previous investigators (Insull, 1954; Steele, 1954; and Kereluk, 1956). In this study, the metabolic costs of recovery were determined by subtracting from the heat production during the recovery period the heat production for an equivalent period of time during the initial resting period.

The food intake records were evaluated for total Calories and for protein and thiamine content, using the short method of dietary analysis proposed by Leichsenring and Wilson (1951) and the food composition tables of Watt and Merrill (1950) and of Bowes and Church (1956).

Data on energy expenditures were treated by analysis of variance (Snedecor, 1956), as shown in Table 4. The analysis of variance was carried out independently for the three age groups and the three weight groups. In each case, there were two degrees of freedom associated with the variation due to groups. The analysis for basal metabolism measurements was based on duplicate observations (two test days) for each subject. The analysis for the other conditions was based on four replications. For those analyses in which the F value indicated that the differences among means were significant, the Q test was used to determine the confidence intervals to be set on mean differences.

Table 4. Plan for analysis of variance of data

Source of variation	Degrees of freedom	
	Basal metabolism	Physical activity
Total	41	83
Groups	2	2
Error	39	81

RESULTS AND DISCUSSION

The experimental design was planned to permit statistical evaluation of the independent influence of age and of body weight on the energy expenditures of the 35 women who participated as subjects. In the following sections, the values for energy expenditures will be presented in terms of various parameters first for the subjects for whom age was a variable factor and then for the subjects for whom weight was a variable factor. Subjects in Group B were young adult women of desirable body weight for their height and ranging in age from 25 to 34 years. This group was used as the reference group for comparison for changes both with age and with variations in body weight.

Variation in Energy Expenditure with Age

Subjects

The three age groups included women in the early, middle and later years of adult life, respectively. The ages, body weights and heights of the subjects, together with the means and the standard error of the means, are given in Table 5. The mean age of young adult women was 29.7±1.3 years; the mean body weight and height were 55.71±2.32 kg. and 163.4±2.2 cm., respectively. There was a span of twenty years between each of the age groups. The women in the middle years, desig-

Table 5. Physical description[a] of subjects in three age groups

Group and subject	Age	Height[a]	Body weight: Observed[a]	Body weight: Desired[b]	Body weight: Deviation	Chest: Lateral	Chest: Antero-posterior	Bi-iliac	Bi-tro-chanteric	Arm girth, rt.	Calf girth, rt.
	yrs.	cm.	kg.	kg.	%	cm.	cm.	cm.	cm.	cm.	cm.
B 1	34	168.2	60.12	61.36	1-2	27.8	21.3	31.5	34.4	24.4	38.1
2	29	165.5	51.26	54.54	5-6	25.0	17.6	27.2	29.6	25.0	33.6
3	32	173.8	65.88	65.91	0-1	28.3	18.4	31.0	32.2	27.7	38.9
4	25	163.3	59.32	60.00	0-1	23.0	18.2	27.6	32.4	28.0	36.4
5	32	155.4	48.82	50.00	2-3	25.1	17.4	26.9	29.9	25.6	34.0
6	31	158.0	52.40	53.64	2-3	26.6	19.0	27.8	31.8	27.3	34.7
7	25	159.5	52.18	52.73	0-1	25.4	19.8	28.8	30.5	26.8	33.0
	29.7[c]	163.4	55.71	56.88	1-2	25.9	18.8	28.7	31.5	26.4	35.5
	±1.3	±2.2	±2.32			±0.7	±0.5	±0.7	±0.6	±0.5	±0.9
D 1	47	174.0	70.24	70.45	0-1	27.1	21.0	34.0	35.5	28.5	36.0
2	47	168.1	55.44	61.82	9-10	26.2	18.8	30.0	32.2	24.0	33.2
3	52	163.0	58.26	59.02	0-1	27.8	18.5	28.9	31.6	29.0	35.8
4	51	145.2	50.34	47.73	6-7	25.2	19.6	25.9	29.9	29.3	30.4
5	45	166.0	60.70	60.91	0-1	26.2	17.8	30.8	32.6	28.5	32.7
6	54	153.5	49.67	50.00	0-1	26.8	19.2	30.0	31.8	27.4	30.2
7	50	173.0	64.92	65.91	0-1	27.8	21.3	31.8	33.9	30.4	34.1
	49.4	163.3	58.51	59.41	2-3	26.7	19.5	30.2	32.5	28.2	33.2
	±1.2	±4.0	±2.84			±0.4	±0.5	±1.0	±0.7	±0.8	±0.9

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[a] Average of two measurements, basal state.

[b] Based on Metropolitan Life Insurance Co. tables (1959) and subjective appraisal.

[c] Mean and standard error.

Table 5. (Continued)

Group and subject	Age	Height	Body weight: Observed	Body weight: Desired	Body weight: Deviation	Chest: Lateral	Chest: Anteroposterior	Bi-iliac	Bitrochanteric	Arm girth, rt.	Calf girth, rt.
	yrs.	cm.	kg.	kg.	%	cm.	cm.	cm.	cm.	cm.	cm.
E 1	69	160.5	56.56	56.82	0-1	28.6	20.2	33.6	34.8	27.8	31.6
2	70	165.5	68.57	65.91	4-5	26.1	21.4	32.3	34.6	31.0	34.5
3	71	153.1	55.82	54.54	2-3	26.8	14.4	30.0	30.9	27.8	32.0
4	67	149.3	59.90	55.91	7-8	26.0	20.6	28.3	34.8	29.1	34.3
5	70	169.6	63.32	63.64	1-2	25.0	22.9	32.2	35.9	26.3	32.8
6	74	155.4	57.56	56.82	1-2	27.2	18.8	30.2	31.9	29.0	32.7
7	65	165.8	66.17	65.45	1-2	29.2	19.8	30.6	34.6	28.0	33.7
	69.4	159.9	61.13	59.87	3-4	27.0	19.7	31.0	33.9	28.4	33.1
	±1.1	±2.8	±1.88			±0.6	±1.0	±0.7	±0.7	±0.6	±0.4

nated as Group D, were in the age range of 45 to 54 years with a mean age of 49.4±1.2 years. The mean body weight was 58.51± 2.84 kg. and the mean height was 163.3±4.0 cm. Although the heights of the women in the two groups were similar and all subjects were considered to be of desirable body weight with respect to age and height, the mean body weight for the women in the fifth and sixth decades exceeded that of the younger women by 2.80 kilograms. The subjects in Group E, the older age group, with ages ranging from 65 to 74 years, were not as tall as the subjects in the younger groups. The mean height for this group was 159.9±2.8 cm. The mean body weight was 61.13±1.88 kg. The decrement in height accompanied by an increase in body weight has been reported by other investigators (Ohlson <u>et al</u>., 1956) for women in the seventh and eighth decades of life. The tendency toward lesser mean stature in the later decades has been attributed in part to a loss of stature with age and in part to the possibility that the maximum adult height of women in this age range may have been less than that of younger women at the present time as a result of less adequate food supplies during the period of growth.

Body measurements of the subjects, in addition to height and weight, are given also in Table 5. There did not appear to be any consistent trend in the lateral and antero-posterior chest measurements which could be associated with age differences. An increment with age was found for the mean bi-iliac (28.7, 30.2 and 31.0 cm.) and bi-trochanteric (31.5, 32.5 and 33.9 cm.) measurements for the young, middle and older age groups, respectively. Although these measurements are selected for use in anthropometry as descriptive of the body frame and are considered to be dependent upon bone size rather than body fat, nevertheless, the presence of subcutaneous fat does influence the measurement obtained. Thus the increase in bi-iliac and bi-trochanteric measurements with age for the women in this series probably reflected an increase in body fat rather than an increase in bone size. The larger calf girth of the young age group was difficult to explain. Some of the subjects in this group may have been accustomed to more walking and standing than the older subjects. Additional anthropometric measurements are given in Table 6. A decrease in hand strength with age was indicated by the mean of the right hand grip measurements; for the young, middle age and older groups these values were 29.0, 24.4 and 21.7 kg., respectively. Ohlson <u>et</u> <u>al</u>. (1956) obtained similar values for their subjects. In accord with the findings of Brožek (1956), the skinfold measurements showed an increase with increase in age. Case histories including information about changes in body weight for each subject are given in Table 24 (in Appendix).

Table 6. Muscle strength and body skinfolds of subjects in three age groups

Group and subject	Age	Body weight	Hand grip		Skinfold			
					Upper arm			
			Right	Left	Right	Left	Front	Back
	yrs.	kg.	kg.	kg.	cm.	cm.	cm.	cm.
B 1	34	60.12	32	30	0.7	0.9	0.6	0.9
2	29	51.26	25	19	1.2	1.0	0.9	1.3
3	32	65.88	24	20	1.4	1.4	1.2	1.5
4	25	59.32	35	31	1.4	1.5	1.0	1.2
5	32	48.82	30	22	1.2	1.3	1.0	1.3
6	31	52.40	28	17	0.9	1.1	1.1	1.0
7	25	52.18	29	22	1.7	1.6	1.2	1.8
	29.7	55.71	29.0	23.0	1.2	1.3	1.0	1.3
	±1.3[a]	±2.32	±1.4	±2.0	±0.1	±0.1	±0.1	±0.1
D 1	47	70.24	28	30	1.1	1.2	0.9	1.4
2	47	55.44	33	28	1.0	1.2	1.2	1.5
3	52	58.26	27	27	1.4	1.4	1.2	1.4
4	51	50.34	23	25	1.7	1.9	1.7	1.8
5	45	60.70	21	24	1.8	1.7	2.2	2.4
6	54	49.67	14	17	0.9	0.8	1.0	1.8
7	50	64.92	25	30	2.0	1.9	2.6	2.0
	49.4	58.51	24.4	25.9	1.4	1.4	1.5	1.8
	±1.2	±2.84	±2.3	±1.8	±0.2	±0.2	±0.2	±0.1
E 1	69	56.56	20	21	1.2	1.2	1.1	2.0
2	70	68.57	26	18	1.7	1.4	1.3	2.0
3	71	55.82	24	16	1.5	1.5	1.3	1.5
4	67	59.90	24	21	1.2	1.3	1.7	1.6
5	70	63.32	16	15	1.6	1.7	2.0	2.1
6	74	57.56	22	21	2.1	1.7	1.8	2.1
7	65	66.17	20	23	1.6	1.4	1.4	2.2
	69.4	61.13	21.7	19.3	1.6	1.5	1.5	1.9
	±1.1	±1.88	±1.3	±1.1	±0.1	±0.1	±0.1	±0.1

[a] Mean and standard error.

Food recall records of the subjects

Food recall records were obtained from each subject for the twenty-four hours preceding each activity test. Mean energy, protein and thiamine values estimated from these records are presented in Table 7.

The mean daily energy values of the diets were: for the young age group, 2249 Calories; for the middle age group, 2302 Calories; and for the older group, 1829 Calories. The means for the protein and thiamine intakes for these three groups were 94.1, 90.0 and 71.2 gm. protein per day and 1.32, 1.86 and 1.14 mg. thiamine per day, respectively.

The recommended dietary allowances (Food and Nutrition Board, National Research Council, 1958), adjusted for body size and age, were used as the point of reference in interpreting the food records. These tables have been used by others to provide a basis for qualitative evaluation of the diets of individuals (Phipard, 1960). The average intakes on the days of the recall records exceeded the mean recommended daily allowances for protein and thiamine. The mean energy value of the women in Group B (25 to 34 years) closely approximated the mean recommended daily allowances for Calories. The diets of the women averaged only 49 Cal./day higher than the average recommended allowance. Variations in intakes among individuals were wide and ranged from 1496 to 3456 Cal./day. Energy values of the diets of the seven sub-

Table 7. Energy value and protein and thiamine content of diets[a] of subjects of three age groups

Group and subject	Calories per day	Protein, gm./day	Thiamine, gm./day
B 1	3456	142.6	1.82
2	2086	96.2	1.24
3	2601	105.4	1.60
4	1496	95.7	1.20
5	2082	73.0	.96
6	1944	82.0	1.29
7	2075	63.8	1.10
Mean	2249	94.1	1.32
Recom. Diet. Allow.[b]	2200	57.0	1.10
D 1	2029	85.2	1.13
2	2768	90.4	1.37
3	1985	102.9	5.32
4	2468	108.0	1.92
5	2066	39.0	.80
6	1898	72.9	1.30
7	1902	80.4	1.19
Mean	2302	90.0	1.86
Recom. Diet. Allow.	2100	59.0	1.05
E 1	2213	78.7	1.25
2	1882	60.0	.97
3	1562	52.7	1.00
4	2084	66.6	1.28
5	1674	87.6	1.33
6	1590	74.0	.94
7	1799	79.1	1.23
Mean	1829	71.2	1.14
Recom. Diet. Allow.	1700	60.0	1.00

[a] Based on recall of diet of preceding 24 hours; average for two days.

[b] Recommended Dietary Allowance (Food and Nutrition Board, National Research Council, 1958) adjusted for desired weight and age, assuming subjects are as active as the 25-year-old "reference" woman.

jects in the older age group averaged 129 Cal./day higher than the recommended dietary allowance.

One-day studies of food intake have been used in other investigations (Trulson et al., 1949) and their use in assessing food intake patterns has been investigated (Bransby et al., 1948; Maynard, 1950; and Young et al., 1953). Two of the possible sources of error in the estimate of food intakes from 24-hour recall records are the errors inherent in the use of food composition tables and the possibility that the day on which the recall diet was obtained deviated considerably from the customary food pattern of the subject.

Basal energy expenditure

The basal oxygen consumptions of the subjects in the three age groups are given in Table 8. An individual value represents the average of four observations except where indicated. Mean basal oxygen consumption for the subjects in the young age group was 9.42 l./hr.; the mean for the subjects in the sixth and seventh decades was 1.29 l./hr. less, or 8.13 l./hr. In contrast, the mean value for the group in the middle years, 9.27 l./hr. was only 0.15 l./hr. less than that of the subjects in early adulthood. Thus a trend toward reduction in basal oxygen consumption did not become apparent for these subjects until the sixth and seventh decades.

The mean basal respiratory quotient of the young adult

Table 8. Basal metabolism of subjects in three age groups

Group and subject		Age	Body weight[a]		Height[a]	Basal oxygen consumption	Basal respiratory quotient	Basal metabolism		
			kg.	kg$^{0.73}$				Cal./hr.	Cal./kg./hr.	Cal./kg$^{0.73}$/hr.
		yrs.			cm.	l./hr.				
B	1	34	60.12	20.12	168.2	11.17	0.89	65.9	1.10	3.31
	2	29	51.26	17.86	165.5	9.91	0.79	55.1	1.08	3.12
	3	32	65.88	21.24	173.8	10.60	0.78	63.0	0.96	2.96
	4	25	59.32	19.90	163.3	8.11	0.80	49.0	0.82	2.48
	5	32	48.82	16.97	155.4	9.45	0.81	51.1	1.04	2.99
	6	31	52.40	18.06	158.0	8.35[b]	0.78[b]	53.2	1.02	2.95
	7	25	52.18	18.12	159.5	8.36	0.87	51.7	0.99	2.88
		29.7	55.71	18.90	163.4	9.42	0.82	55.6	1.00	2.96
		±1.3[c]	±2.32	±0.58	±2.2	±0.45		±2.4	±0.04	±0.10
D	1	47	70.24	22.42	174.0	9.28	0.83	58.0	0.83	2.60
	2	47	55.44	19.05	168.1	8.65	0.86	43.9	0.78	2.34
	3	52	58.26	19.64	163.0	11.38[b]	1.07[b]	61.4	1.05	3.15
	4	51	50.34	17.73	145.2	7.96	0.93	46.3	0.92	2.66
	5	45	60.70	20.08	166.0	10.62	0.97	61.1	1.01	3.05
	6	54	49.67	17.44	153.5	7.86	0.79	49.7	1.00	2.87
	7	50	64.92	21.32	173.0	9.15	0.86	55.6	0.86	2.64
		49.4	58.51	19.67	163.3	9.27	0.87	.7	0.92	2.76
		±1.2	±2.84	±0.68	±4.0	±0.50		±2.7	±0.03	±0.11

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[a] Average of two measurements, basal state.

[b] Based on one day only.

[c] Mean and standard error.

Table 8. (Continued)

Group and subject	Age	Body weight kg.	Body weight kg$^{0.73}$	Height	Basal oxygen consumption	Basal respiratory quotient	Basal metabolism Cal./hr.	Basal metabolism Cal./kg./hr.	Basal metabolism Cal./kg$^{0.73}$/hr.
	yrs.			cm.	l./hr.				
E 1	69	56.56	19.20	160.5	6.90	0.97	48.2	0.85	2.53
2	70	68.57	22.12	165.5	8.08	0.73	43.3	0.63	1.99
3	71	55.82	19.04	153.1	6.36^{b}	0.77^{b}	50.5	0.90	2.68
4	67	59.90	20.02	149.3	9.59	1.00	53.9	0.90	2.72
5	70	63.32	20.56	169.6	8.64	1.03	54.9	0.87	2.66
6	74	57.56	19.42	155.4	7.61	0.81	47.8	0.83	2.48
7	65	66.17	21.44	165.8	9.74	0.85	55.6	0.84	2.60
	69.4	61.13	20.26	159.9	8.13	0.86	50.6	0.83	2.52
	±1.1	±1.88	±0.45	±2.8	±0.49		±1.7	±0.04	±0.09

women was 0.82 (Table 8) and corresponded to the fasting respiratory quotient which is considered generally to represent the ratio of carbon dioxide production to oxygen consumption for healthy adults on a mixed diet. The range in values for the group was from 0.78 to 0.89, with five subjects below and two above the mean value of 0.82.

Mean values for the other two groups were higher than for the young adult women. The ranges for these groups were 0.79 to 1.07 with a mean of 0.87 and 0.75 to 1.03, with a mean of 0.86 for Groups D and E, respectively. Values for respiratory quotients lower than 0.7 and above 1.0 have been reported (DuBois, 1936). That one or more of the respiratory quotients should be above this range was not surprising. The concentration of high values for respiratory quotients among the middle aged and older women was unexpected. Only two of seven values for the women ranging in age from 45 to 54 were below 0.85. Three of the seven values for women 65 to 75 years of age were below 0.82. Less confidence can be placed in the value of 1.07 for subject 3D than for most of the other values since this value represented measurements on one day only. This was not true, however, for subjects 5D, 1E and 5E. Duplicate values on each of two days were consistently high for these subjects. Swift and French (1954) as well as DuBois (1936) have discussed the problems involved in the determination of the respiratory quotient and, particularly, the influence of hyperventilation. These authors caution against the interpretation of high values for respiratory quotients as indicative of increased carbohydrate oxidation since such values may result simply from hyperventilation. It is recognized that some people in older age groups may experience discomfort during the basal metabolism determination to a greater extent than younger people. Among the subjects in this study, this was true particularly when dentures were worn since the mouthpiece was less comfortable with dentures and yet could not be held securely if the dentures were removed. It is possible that there was hyperventilation by subjects who experienced discomfort during the test. Only subjects 1E and 5E made comments which would indicate that the procedure was difficult for them.

The basal metabolisms of the subjects in the three age groups are given also in Table 8. Values have been expressed on an hourly basis in terms of total Calories, Calories per kilogram and per kilogram of body weight raised to the 0.73 power.

For the subjects in early adulthood, the mean energy expenditure in Calories per hour was 55.6±2.4. In comparison, the subjects in the middle years, with a mean energy expenditure of 53.7±2.7 Cal./hr. averaged two Cal./hr. less than the younger subjects. The mean energy expenditure of the older subjects in the basal state was 50.6±1.7 Cal./hr., or three

Cal./hr. less than that of the middle age group and five Cal./hr. less than that of the women in early adulthood. Values for individual subjects were within ranges of 17, 18 and 12 Cal./hr. for the young, middle age and older groups, respectively.

The trend toward a reduction in basal metabolism with age was apparent from the mean values for the three groups when energy expenditure was expressed in Calories per kilogram of body weight as well as in Calories per kilogram of body weight raised to the 0.73 power. Analysis of variance indicated that the reduction in basal metabolism with advancing age was significant ($P \leq 0.01$) when body weight was used as a basis for expression, both to the first power and to the 0.73 power. The basal energy expenditures of the three age groups, however, were not significantly different when Calories per hour were compared. Although there was a decrement in mean basal Calories per hour with advancing age for the three groups, the variation among individuals apparently was such that the differences were not significant for the number of subjects in the study. The range of values, in Calories per hour, was from 49.0 to 65.9 for Group B, ages 25 to 34, from 43.9 to 61.4 for women aged 45 to 54 and 43.3 to 55.6 for women in the seventh and eighth decades.

Although the women in the three age groups were selected for participation on the basis of body weight in relation to height and age and were considered to be of desirable body weight for their frame and stature, there was an increase in mean body weights for the three age groups corresponding to the increase in age. Thus when basal metabolisms were expressed on the basis of body weight, the total heat production was influenced to a slightly greater extent by the body weights of the women in Group E than by those of the women in Group B. Values for Group B ranged from 0.82 to 1.10 Cal./kg./hr.; values for Group D, ages from 45 to 54 years, ranged from 0.78 to 1.05 Cal./kg./hr. The range for the women in the seventh and eighth decades, Group E, was from 0.63 to 0.90 Cal./kg./hr.

The use of $W_{kg.}^{0.73}$ as a basis for expression of energy expenditures had an effect on the values similar to that of body weight to the first power. Since the deviations from desirable body weight were relatively small and the differences in mean body weights among the three groups also were relatively small, it is not surprising that the values were similarly affected by expression on the basis of body weight and on body weight raised to the 0.73 power.

Of the three bases used for the expression of energy expenditure, $W_{kg.}^{0.73}$ has been considered to be most closely related to metabolic size. Various formulae or equations for estimating surface area have been widely used also with the purpose of expressing body size in terms of metabolically active tissue. Shock and Yeingst (1955) and Leverton <u>et al</u>. (1957) found that there was a decrease in basal metabolism expressed as Calories per square meter per hour with advancing age. The decrease with age in basal metabolism expressed as Calories per body weight to the 0.73 power per hour observed for the subjects in this study is in accord with that reported by Leverton and Shock and Yeingst.

Energy expenditure during physical activity

The energy expenditure of the subjects in the three age groups are given in Table 9 for the resting state and for two degrees of activity, that is, walking on a treadmill at two miles per hour at a four per cent incline and at three miles per hour at a four per cent incline. Since the rate of incline was constant for the two rates of walking, the activities differed essentially in work per unit of time rather than in the amount of work involved in the activity. The activities were carried out on two days. Each value represents the average of two observations, made on different days. The data are presented graphically in Figure 2.

Energy expenditure during resting was measured immediately preceding the work on the treadmill. The subjects were at bed-rest and awake. Mean energy expenditures for the three age groups were 66.6±2.5, 64.2±2.7 and 56.8±1.4 Cal./hr., respectively. These values were 11, 10.5 and six Cal./

Table 9. Energy expenditures during walking of subjects in three age groups

					Walking					
		Resting			2 m.p.h., 4% incline			3 m.p.h., 4% incline		
Group and subject	Age	Cal. /hr.	Cal./kg. /hr.	Cal. $/kg^{0.73}$ /hr.	Cal. /hr.	Cal./kg. /hr.	Cal. $/kg^{0.73}$ /hr.	Cal. /hr.	Cal./kg. /hr.	Cal. $/kg^{0.73}$ /hr.
	yrs.									
B 1	34	74.9[a]	1.23	3.72	224.8	3.68	11.17	244.0	4.00	12.12
2	29	63.6	1.23	3.56	195.0	3.76	10.92	245.3	4.73	13.74
3	32	74.7	1.14	3.52	233.1	3.54	10.98	273.3	4.16	12.87
4	25	56.6	0.94	2.85	222.4	3.70	11.18	280.7	4.66	14.10
5	32	63.9	1.32	3.77	150.4	3.11	8.86	203.0	4.20	11.96
6	31	68.0	1.29	3.76	178.4	3.39	9.88	216.2	4.10	11.97
7	25	64.7	1.22	3.58	226.8	4.28	12.51	290.4	5.48	16.02
	29.7	66.6	1.20	3.54	204.4	3.64	10.79	250.4	4.48	13.26
	±1.3[b]	±2.5	±0.05	±0.12	±11.7	±0.14	±0.43	±12.5	±0.21	±0.55
D 1	47	69.6	0.98	3.10	297.9	4.20	13.29	382.4	5.40	17.06
2	47	65.8	1.16	3.45	210.6	3.72	11.06	285.5	5.04	14.99
3	52	71.8	1.21	3.57	213.1	3.60	10.85	280.6	4.74	14.28
4	51	56.2	1.09	3.17	143.2	2.79	8.08	200.6	3.90	11.32
5	45	66.7	1.09	3.32	208.7	3.42	10.39	246.5	4.04	12.28
6	54	52.1	1.04	2.99	171.1	3.41	9.82	196.9	3.92	11.30
7	50	67.0	1.01	3.14	209.4	3.17	9.82	235.0	3.56	11.02
	49.4	64.2	1.08	3.25	207.7	3.47	10.48	261.1	4.37	13.18
	±1.2	±2.7	±0.03	±0.76	±18.0	±0.17	±0.59	±24.1	±0.26	±0.87

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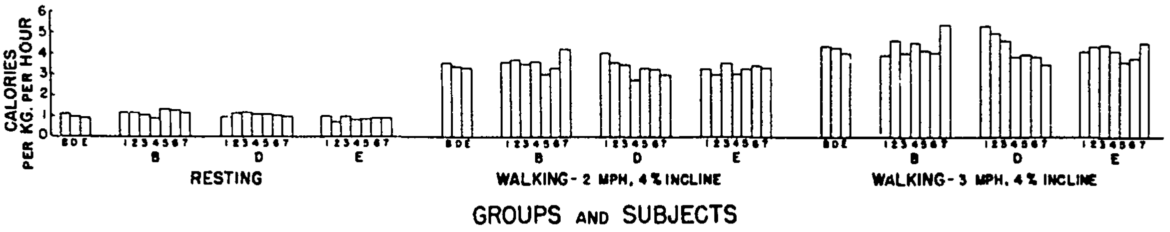
[a] Average of measurements on two days.

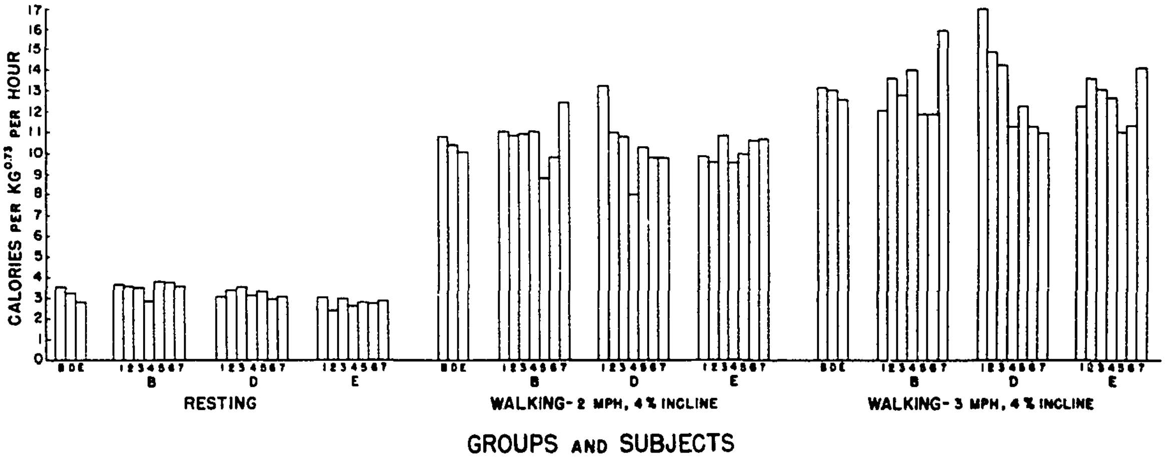
[b] Mean and standard error.

Table 9. (Continued)

Group and subject	Age	Resting			Walking					
					2 m.p.h., 4% incline			3 m.p.h., 4% incline		
		Cal. /hr.	Cal./kg. /hr.	Cal. /kg$^{0.73}$ /hr.	Cal. /hr.	Cal./kg. /hr.	Cal. /kg$^{0.73}$ /hr.	Cal. /hr.	Cal./kg. /hr.	Cal. /kg$^{0.73}$ /hr.
	yrs.									
E 1	69	60.9	1.06	3.17	190.2	3.32	9.90	237.5	4.15	12.37
2	70	53.0	0.76	2.40	212.3	3.06	9.60	303.4	4.36	13.72
3	71	57.2	1.02	3.03	206.5	3.65	10.85	251.8	4.45	13.23
4	67	52.6	0.87	2.63	191.7	3.16	9.58	255.4	4.21	12.76
5	70	58.1	0.92	2.82	206.3	3.28	10.03	228.0	3.62	11.08
6	74	54.3	0.93	2.80	207.3	3.56	10.68	221.4	3.80	11.40
7	65	61.8	0.93	2.88	230.4	3.46	10.74	305.2	4.58	14.24
	69.4	56.8	0.93	2.82	206.4	3.36	10.20	257.5	4.17	12.69
	±1.1	±1.4	±0.04	±0.09	±5.1	±0.08	±0.19	±12.9	±0.13	±0.43

Figure 2. Variations in energy expenditure during walking tests by subjects in three age groups expressed in three parameters


CALORIES PER KG. PER HOUR
0
1
2
3
4
5
6
BDE
1234567
B
D
E
RESTING
WALKING - 2 MPH, 4% INCLINE
WALKING - 3 MPH, 4% INCLINE
GROUPS AND SUBJECTS


CALORIES PER KG$^{0.73}$ PER HOUR
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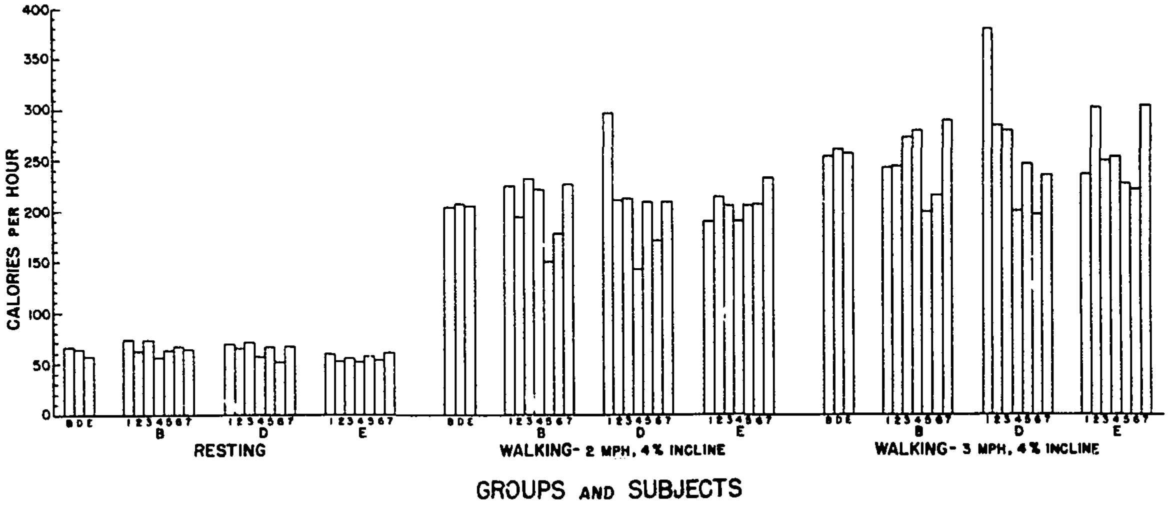
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
BDE
1234567
B
D
E
RESTING
WALKING - 2 MPH, 4% INCLINE
WALKING - 3 MPH, 4% INCLINE
GROUPS AND SUBJECTS


CALORIES PER HOUR
0
50
100
150
200
250
300
350
400
BDE
1234567
B
D
E
RESTING
WALKING - 2 MPH, 4% INCLINE
WALKING - 3 MPH, 4% INCLINE
GROUPS AND SUBJECTS

hr. above the mean energy expenditure during the basal state for the three age groups, respectively. Thus energy expenditure during resting was 21.6 and 19.6 per cent, respectively, above basal heat production for subjects in the young and middle age groups whereas the increment for women in the seventh and eighth decades was only 12.2 per cent.

The post-absorptive period preceding the measurement of basal metabolism was 12 to 14 hours in length; the energy expenditure during resting was measured approximately two hours after lunch. Therefore the higher values for energy expenditure during resting in comparison with basal energy expenditure may have included heat production associated with the specific dynamic action of foodstuffs, digestion and utilization of nutrients. The measurement of basal metabolism was preceded by at least eight hours of bed-rest and only light activity associated with coming to the laboratory. In contrast, the women carried out various types of activities in the morning preceding the measurement of oxygen consumption in the resting period. In each instance, there was a rest period of 30 minutes before measurement of oxygen consumption. However, this period may not have been long enough to offset the influence of morning activity on energy metabolism and a residual effect may account in part for the higher values for energy expenditure of the subjects during resting as compared with basal metabolism.

A tendency toward reduction of food intake with age has been reported (Swanson et al., 1955). Greater physical activity in the morning by the women in the third and fourth decades and possibly a greater intake of food at the noon meal may have contributed to the higher increments in energy expenditure above basal metabolism for these subjects during resting as compared with the women in the seventh and eighth decades. The increment in energy expenditure for the women in the fifth and sixth decades was similar to that for the women in the younger age group.

The apparent reduction in basal metabolism with advancing age was not statistically significant when analysis of variance was carried out on energy expenditures expressed as Calories per hour. In contrast, the differences among the energy expenditures during resting for the three age groups were statistically significant ($P \leq 0.01$) when the values were expressed as Calories per hour. There also was a significant difference among energy expenditures of the three age groups when the values were expressed on the basis of body weight.

It might be expected that the factors which contributed to the greater differences among mean energy expenditures during resting as compared with the basal state might also contribute to a greater variation among individuals. However the standard errors were of the same magnitude for the means of the basal metabolisms of the three groups and the means of the energy expenditures during resting.

For the young subjects the total energy expenditure in Calories per hour averaged 204.4±11.7 during walking at two miles per hour and 250.4±12.5 during walking at three miles per hour. Corresponding mean values for the middle age group were 207.7±18.0 and 261.1±24.1, and for the older age group, 206.4±5.1 and 257.5±12.9 Cal./hr., respectively. The increases in walking at three miles per hour over two miles per hour were 46, 53 and 51 Cal./hr., respectively, or 22.5, 25.7 and 24.8 per cent. The extent of variation among individuals is apparent from Figure 2, but the mean metabolic cost of walking at the moderate rate of speed was about the same for all three groups.

Mean energy expenditures during walking at two rates of speed on two different test days are shown in Table 10. For the young subjects these means were 211.1 and 197.7 Cal./hr. at two miles per hour and 246.8 and 254.0 Cal./hr. at three miles per hour. The differences between Day 1 and Day 2 were -13.4 Cal./hr. at two miles per hour and +7.2 Cal./hr. at three miles per hour. Differences between the means for the first day and the second day were greater for the women, ages 45 to 54 years, than for women ranging in age from 65 to 74 years. Women in the seventh and eighth decades of life may be accustomed to regulating their pace of activity more carefully than

Table 10. Comparison between days of mean energy expenditures during walking by women of different ages

Age group	No. of subjects	Calories per hour 2 m.p.h., 4% incline Day 1	 Day 2	 3 m.p.h., 4% incline Day 1	 Day 2
25 to 34 yrs.	7	211.1±12.1[a]	197.7±12.7	246.8±13.0	254.0±13.0
45 to 54 yrs.	7	221.2±21.9	194.3±15.2	273.1±28.2	249.0±21.5
65 to 74 yrs.	7	210.9±6.3	201.8±10.0	256.0±10.3	259.1±16.0

[a] Standard error of the mean.

younger women; if so, this may account for the small difference in energy expenditure between means for Day 1 and Day 2 for Group E.

The mean energy expenditures in Calories per kilogram per hour were 3.64±0.14, 3.47±0.17 and 3.36±0.08 at two miles per hour and 4.48±0.21, 4.37±0.26 and 4.17±0.13 at three miles per hour, respectively, for the young, middle and older age groups. For all three groups the increase in walking at three miles per hour over two miles per hour was 0.8 to 0.9 Cal./kg./hr. There was approximately the same increase with walking at the faster rate of speed for all three age groups.

Similar results were obtained when energy expenditure was expressed as Cal./kg$^{0.73}$/hr. For all three groups energy expended during walking at two miles per hour was approximately 10 Cal./kg$^{0.73}$/hr.; at three miles per hour, approximately

13 Cal./kg.$^{0.73}$/hr. Mean energy expenditures at the two rates of speed in Cal./kg.$^{0.73}$/hr. were 10.79±0.43, 10.48±0.59 and 10.20±0.19; and 13.26±0.55, 13.18±0.87 and 12.69±0.43, respectively, for the young, middle and old groups. Increases in walking at three miles per hour over two miles per hour were 2.47, 2.70 and 2.49 Cal./kg.$^{0.73}$/hr., respectively, for these three groups.

Although there was an apparent decrease in energy expenditure with increase in age when expenditure was expressed in units related to body weight, statistical treatment indicated that there was no real decrease. Analysis of the variance gave F values as follows for comparisons among groups: Cal./hr., F = 0.15; Cal./kg./hr., F = 1.40; and Cal./kg.$^{0.73}$ /hr., F = 0.57. Therefore it appears that age *per se* was not a factor influencing gross energy expenditure during walking for these subjects under the conditions of this study.

The increment in energy expenditure during walking was calculated to assess the metabolic cost of walking with respect to energy metabolism. The increment was expressed as the difference between the energy expended during walking and during resting immediately preceding the activity (Table 11).

On the basis of Calories per hour, the means indicated a tendency toward an increase in increment with an increase in age. These increments were 138, 144 and 149 Cal./hr. at two milrs per hour and 184, 197 and 201 Cal./hr. at three miles

Table II. Mean increment in energy expended during walking by subjects in three age groups

		Rate					
		2 m.p.h., 4% incline			3 m.p.h., 4% incline		
Age groups	Number of subjects	Cal. /hr.	Cal. /kg. /hr.	Cal. /kg.$^{0.73}$ /hr.	Cal. /hr.	Cal. /kg. /hr.	Cal. /kg.$^{0.73}$ /hr.
25 to 34 yrs.	7	138	2.59	7.25	184	3.28	9.72
45 to 54 yrs.	7	144	2.39	7.08	197	3.29	9.93
65 to 74 yrs.	7	149	2.43	7.38	201	3.24	9.86

per hour for the young, middle and older age groups, respectively. The differences among means were not, however, statistically significant.

The values, expressed as Calories per kilogram per hour, for the two rates of walking, were 2.59 and 3.28 for the young adults, 2.39 and 3.29 for the subjects in the middle years and 2.43 and 3.24 for women in the seventh and eighth decades. When the basis of expression was weight to the 0.73 power, the mean increments were 7.25, 7.08 and 7.38 Cal./kg.$^{0.73}$/hr. for walking at two miles per hour and 9.72, 9.93 and 9.86 Cal./kg.$^{0.73}$/hr. for walking at three miles per hour, respectively, for Groups B, D and E. Analysis of varience indicated that the differences among means for the increment in energy expenditure for walking for the three age groups were not significant, either on the basis of hourly Calories per kilogram of body weight to the first power or to the 0.73 power.

The results discussed previously demonstrated that age affected the energy expenditure of basal metabolism and of the resting state of the three groups; that is, the energy expenditures in the basal state and during resting decreased with an increase in age. Conversely, there was not a significant difference among the age groups with respect to energy expenditures during walking. To some extent these findings may have been influenced by factors such as differences in mean body weights of the three groups of women and by the extent of variation among individuals within each group. The data indicate, however, that the metabolic cost of physical activity was not affected by age. Since the metabolic cost of walking for these subjects, on the basis of Calories per hour, was approximately three times as great as the energy expenditure in the basal state, the total energy expended during walking reflected the metabolic cost of the activity to a greater extent than the basal energy expenditure.

The difficulty in segregating a single characteristic of an individual from the many factors which contribute to his biochemical individuality (Williams, I956) has been recognized increasingly as understanding of the multiple interrelationships of these factors has developed. Thus it is recognized that aging per se might contribute to either an increase or a decrease in the metabolic cost of a physical activity but that this effect might be counteracted by an opposing influence of other characteristics of an individual. The possible extent of influence of the differences in mean body weights of the three groups on the metabolic cost of walking can be evaluated more adequately after consideration of the data to be presented in the next section.

Variation in Energy Expenditure with Body Weight

Selection of weight classifications

Evaluation of weight status of subjects participating in a human nutrition study based upon tables of desirable weights of the Metropolitan Life Insurance Company is a common practice. Keys and Brožek (I953) have emphasized the limitations of such evaluations. At the outset of this study when the subjects were being selected use was made of the Metropolitan Life Insurance Company tables then available (I95I). The new tables published in I959 were used to reappraise the desired weights of the subjects. Evaluations of body frame from anthropometric measurements and clinical appraisals of muscular development and of subcutaneous fat deposits aided in the estimation of the desirable weight for each subject.

The weight classifications selected for use were as follows: average weight, from -10 to +15 per cent of desirable weight; overweight, more than 15 per cent above desirable weight; and underweight, more than 10 per cent below desirable weight. This grouping is in accord with that used by Hawthorne (1954). The body weights of the subjects in the age groups discussed above were all within 10 per cent of desirable weight.

Other investigators have defined overweight and underweight in different ways. Distinctions in degrees of underweight and overweight made by Dublin and Lotka (1936) in their work with the Metropolitan Life Insurance Company statistics, included, for overweight, three groups: namely, five to 14 per cent, 15 to 24 per cent, and more than 25 per cent above average weight. They classed those whose weights were -5 to -14 per cent of average as moderately underweight, and those whose weights were -15 to -34 per cent of average as severely underweight. Classifications of caloric undernutrition were defined by Keys (1950) as "slight" when the body weight was no greater than -10 per cent of desirable weight; "moderate", between -10 to -20 per cent underweight; "severe", between -20 and -30 per cent underweight; and "extreme", greater than 30 per cent underweight. Overweight has been defined as "any deviation of 10 per cent or more above the ideal weight for the person . . . ." (Armstrong, 1951). Individuals 10 per cent above or below the standard weights from the tables of Davenport (1923) were classed as overweight and underweight, respectively, in a nutritional status study of Groton Township, New York (Moore and Shaw, 1950).

Subjects

The women were young adults ranging in age from 25 to 34 years and were distributed among three groups according to body weight: underweight, desirable weight, and overweight. There were seven in each group. The women in Group B were of desirable body weight for their stature and comprised the reference group for study of the influence of body weight on energy expenditure. This group also was the reference group for evaluation of the influence of age on energy expenditure. Physical measurements of the subjects are given in Table 12. The mean age for the underweight group was 26.4±0.7 yrs., and the mean weight and height were 50.62±1.45 kg. and 169.1±0.9 cm., respectively. As stated previously, the mean age for the young women in the average weight group was 29.7±1.3 yrs., and mean values for weight and height were 55.71±2.32 kg. and 163.4±2.2 cm., respectively. Corresponding values for the overweight group were 29.1±0.8 yrs., 73.79±5.26 kg. and 164.5 ±2.1 cm., respectively.

Beaudoin *et al*. (1953) have discussed "active" and "static" status of body weight and reviewed the implications

Table 12. Physical description of subjects in three weight groups

Group and subject	Age	Height[a]	Body weight			Chest		Bi-iliac	Bi-trochanteric	Arm girth, rt.	Calf girth, rt.
			Observed[a]	Desired[b]	Deviation	Lateral	Anteroposterior				
	yrs.	cm.	kg.	kg.	%	cm.	cm.	cm.	cm.	cm.	cm.
A 1	26	173.4	56.40	65.91	12-13	24.9	19.4	31.5	32.3	22.7	33.3
2	30	168.8	52.88	60.91	12-13	23.4	17.9	30.1	31.4	22.7	33.2
3	25	168.2	46.75	56.82	18-19	25.6	13.0	27.2	30.6	20.7	33.0
4	28	167.6	48.87	56.82	18-19	24.5	17.2	31.2	30.3	24.7	33.8
5	25	171.2	51.40	58.18	11-12	26.0	16.1	29.0	32.5	23.0	32.8
6	25	166.4	52.62	59.09	10-11	25.4	19.2	27.3	30.3	24.0	33.7
7	26	168.2	45.42	58.18	20-21	23.6	17.7	25.6	28.8	20.8	32.0
	26.4[c]	169.1	50.62	59.42	13-14	24.8	17.2	28.8	30.9	22.7	33.1
	±0.7	±0.9	±1.45			±0.4	±0.8	±0.8	±0.5	±0.56	±0.2
B 1	34	168.2	60.12	61.36	1-2	27.8	21.3	31.5	34.4	24.4	38.1
2	29	165.5	51.26	54.54	5-6	25.0	17.6	27.2	29.6	25.0	33.6
3	32	173.8	65.88	65.91	0-1	28.3	18.4	31.0	32.3	27.7	38.9
4	25	163.3	59.32	60.00	0-1	23.0	18.2	27.6	32.4	28.0	36.4
5	32	155.4	48.82	50.00	2-3	25.1	17.4	26.9	29.9	25.6	34.0
6	31	158.0	52.40	53.64	2-3	26.6	19.0	27.8	31.8	27.3	34.7
7	25	159.5	52.18	52.73	0-1	25.4	19.8	28.8	30.5	26.8	33.0
	29.7	163.4	55.71	56.88	1-2	25.9	18.8	28.7	31.5	26.4	35.5
	±1.3	±2.2	±2.32			±0.7	±0.5	±0.7	±0.6	±0.5	±0.9

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[a] Average of two measurements, basal state.

[b] Based on Metropolitan Life Insurance Co. tables (1959) and subjective appraisal.

[c] Mean and standard error.

Table 12. (Continued)

Group and subject	Age	Height	Body weight			Chest		Bi-iliac	Bi-trochanteric	Arm girth, rt.	Calf girth, rt.
			Observed	Desired	Deviation	Lateral	Antero-posterior				
C 1	25	166.1	65.92	58.18	14-15	26.7	20.8	30.9	33.4	31.4	35.5
2	30	164.9	70.74	58.18	21-22	26.8	20.4	35.0	33.8	31.2	38.2
3	30	160.0	67.68	59.09	14-15	28.2	15.4	29.4	31.6	33.0	36.8
4	32	154.3	57.90	51.82	15-16	25.2	19.0	31.2	32.8	28.3	34.6
5	28	170.0	92.02	68.18	35-36	31.3	22.2	33.8	36.4	35.2	40.0
6	29	167.0	67.72	59.09	16-17	27.4	20.8	32.1	34.7	30.0	37.8
7	30	169.0	94.56	63.64	49-50	29.3	23.1	33.8	37.6	37.0	42.2
	29.1	164.5	73.79			27.8	20.2	32.3	34.3	32.3	37.9
	±0.8	±2.1	±5.26			±0.8	±0.9	±0.8	±0.8	±1.1	±1.0

of body weight. All of the subjects were considered "static" in their weight patterns with the exception of Subjects 5C, 6C and 7C in the overweight group. Subjects 5C and 7C were making conscious efforts to lose weight by regulation of daily caloric intake; both had undergone definite changes in body weight during the previous year. The weight history of Subject 6C indicated a pattern of alternate gains and losses in an attempt to attain and maintain desirable weight. Information about changes in body weight and a brief medical history for each subject are given in Table 24 (in Appendix).

There was an increment in the means of the various body measurements which tended to parallel the increment in mean weight between Groups A and B and between Groups B and C. Exceptions to this were the bi-iliac and bi-trochanteric measurements for which there was essentially no difference between mean values for the underweight women and the average weight women. Bi-iliac diameters were 28.8 and 28.7 cm. for Groups A and B. The overweight group, Group C, averaged 32.3 cm. The standard errors of the means were all of the same magnitude. The bi-trochanteric measurement was 30.9±0.5 cm.for the underweight women and 3I.5±0.6 cm. for the women of desirable weight. The mean value for the overweight subjects was 34.3±0.8. The difference between the mean values for the average weight women and the overweight women was similar to or greater for both lateral and antero-posterior chest measurements than the difference between means for the underweight and the average weight group. The lateral chest measurements averaged 24.8±0.4, 25.9±0.7 and 27.8±0.8 cm. and the antero-posterior chest measurements averaged 17.2±0.8, 18.8 ±0.5 and 20.2±0.9 cm., for the under-, average and overweight groups, respectively. Of the body measurements which were made, the lateral and antero-posterior chest measurements and the bi-iliac and bi-trochanteric measurements probably reflect body frame to a greater degree than other measurements. Or, conversely, these measurements may be less likely to be affected by subcutaneous fat than the other body measurements, excepting skinfolds. Thus it would seem that the skeletal size of the women in Group A was similar to that of Group B but that the women in Group C may have had a broader frame as well as a greater amount of body fat than the women of desirable body weight. Since the difference in mean weights of Groups A and B was only 5.1 kg. in comparison to a difference of 18.1 kg. between Groups B and C, it is possible however that the differences between means of the three weight groups were influenced primarily by body fat.

Both the arm girth and calf girth measurements are influenced by the thickness of the fat pad as well as the bone size. The right arm girths for the average weight women averaged 3.7 cm. more than for the underweight women and 5.9 cm. less than for the overweight women. Mean values for the right calf girth were 2.4 cm. less for the underweight than for the average weight women and 2.4 cm. more for the overweight than for the average weight subjects.

Few studies relating anthropometry to nutritional status of women have appeared in the literature. Ohlson _et al_. (1956) used methods of measurement similar to those used in this study. Table 13 presents a comparison of some body measurements of the weight groups in the present study with those of selected groups of average weight, overweight and underweight in the investigation reported by Ohlson _et al_. (1956). The measurements of the women in the two studies were similar in magnitude even though the subjects reported by Ohlson _et al_. represented a greater range of age.

Measurements of muscle strength and body skinfolds are shown in Table 14. There was greater variation among individuals for the hand grip expressed in kilograms within Groups A and C than within Group B; the mean for the right hand grip of the average weight women was larger than the means for the other two groups. Values for the left hand grip were similar among the three groups. The hand grip measurements were lower than values reported by Ohlson _et al_. (1956); the reported values were for women many of whom were in employment which involved physical labor. In contrast the subjects of this study were professional women and may have been less active physically.

Table 13. Comparison of body measurements of subjects in three weight groups with reported values

Subjects	No.	Age range	Height	Weight range	Chest		Arm girth, rt.	Bi-iliac	Bi-tro-chan-teric	Calf girth, rt.
					Lateral	Antero-posterior				
		yrs.	cm.	kg.	cm.	cm.	cm.	cm.	cm.	cm.
<u>Underweight</u>										
Group A	7	25-34	169.1	45.4-56.4	24.8	17.2	22.7	28.8	30.9	33.1
Ohlson *et al.* (1956)	7	25-51	163.4	45.0-54.8	23.9	16.6	23.5	26.7	30.8	32.3
<u>Average weight</u>										
Group B	7	25-34	163.4	48.8-65.9	25.9	18.8	26.4	28.7	31.5	35.5
Ohlson *et al.* (1956)	7	25-52	164.8	53.5-69.9	25.4	17.9	27.6	28.3	31.8	35.9
<u>Overweight</u>										
Group C	7	25-34	164.5	57.9-94.6	27.8	20.2	32.3	32.3	34.3	37.9
Ohlson *et al.* (1956)	7	25-57	164.5	76.2-112.0	27.2	22.5	33.4	33.0	36.4	40.0

Table 14. Muscle strength and body skinfolds of subjects in three weight groups

Group and subject	Age	Body weight	Hand grip		Skinfold			
					Upper arm			
			Right	Left	Right	Left	Front	Back
	yrs.	kg.	kg.	kg.	cm.	cm.	cm.	cm.
A 1	26	56.40	40	31	0.6	0.8	0.6	1.0
2	30	52.88	20	18	0.7	0.8	0.7	1.4
3	25	46.75	22	8	1.1	1.0	0.6	0.9
4	28	48.87	25	29	0.4	0.5	0.8	0.8
5	25	51.40	26	26	1.2	1.3	1.3	1.2
6	25	52.62	25	30	1.0	0.9	0.9	0.9
7	26	45.42	21	18	0.5	0.5	0.7	0.8
	26.4	50.62	25.6	22.8	0.8	0.8	0.8	1.0
	±0.7[a]	±1.45	±2.6	±1.0	±0.12	±0.11	±0.09	±0.08
B 1	34	60.12	32	30	0.7	0.9	0.6	0.9
2	29	51.26	25	19	1.2	1.0	0.9	1.3
3	32	65.88	24	20	1.4	1.4	1.2	1.5
4	25	59.32	35	31	1.4	1.5	1.0	1.2
5	32	48.82	30	22	1.2	1.3	1.0	1.3
6	31	52.40	28	17	0.9	1.1	1.1	1.0
7	25	52.18	29	22	1.7	1.6	1.2	1.8
	29.7	55.71	29.0	23.0	1.2	1.3	1.0	1.3
	±1.3	±2.32	±1.4	±2.0	±0.13	±0.10	±0.08	±0.11
C 1	25	65.92	18	26	1.8	2.1	1.4	2.6
2	30	70.74	30	23	1.6	1.6	1.5	2.2
3	30	67.68	28	27	2.7	2.5	2.9	3.5
4	32	57.90	24	22	1.2	1.1	1.3	1.9
5	28	92.02	32	31	2.6	2.5	2.4	3.5
6	29	67.72	19	12	1.8	2.1	2.2	2.3
7	30	94.56	35	22	2.7	2.9	2.5	3.9
	29.1	73.79	26.6	23.3	2.1	2.1	2.0	2.8
	±0.8	±5.26	±2.4	±2.2	±0.23	±0.23	±0.24	±0.29

[a] Mean and standard error.

Values are given for four skinfolds. The sum of the average skinfold measurements for Group A was 3.41 cm. The mean of each of the skinfolds for Group B was higher than that for Group A. The total of the four skinfold means for Group B was 4.76; the total for Group C was 9.04 cm. The relatively large skinfold values for the subjects of Group C in comparison to the other subjects are in accord with the reports of Brožek (1956), Ohlson _et al_. (1956) and others that skinfold thicknesses vary directly with the amount of fat on the body and with the degree of overweight.

Energy value, protein and thiamine of diets

Estimations of the energy value and the protein and thiamine content of the diets of the 21 subjects are given in Table 15. The estimations were based on two 24-hour recall records. Mean energy values of the diets of the three groups were 2083, 2249 and 1949 Calories per day for Groups A, B and C, respectively. The mean energy value was approximately 210 Calories per day less than the mean recommended dietary allowance for Calories (Natl. Acad. Sci. - Natl. Res. Council, 1958). Only two subjects reported diets with an energy value above the recommended allowance for Calories.

The energy value of the diets of women who were classified as overweight ranged from 1508 to 2742 Calories per day with a mean of 1949 Cal./day. Five of the women had diets

Table 15. Energy value and protein and thiamine content of diets[a] of subjects of three weight groups

Group and subject	Calories	Protein	Thiamine
		gm.	mg.
A 1	2081	102.9	1.29
2	2453	77.8	1.13
3	1068	39.4	0.66
4	1988	77.2	1.10
5	2060	87.2	1.18
6	1980	86.8	1.10
7	2950	116.4	1.80
Mean	2083	83.9	1.19
Recom. Diet. Allow.[b]	2300	59.0	1.15
B 1	3456	142.6	1.82
2	2086	96.2	1.24
3	2601	105.4	1.60
4	1496	95.7	1.20
5	2082	73.0	0.96
6	1944	82.0	1.29
7	2075	63.8	1.10
Mean	2249	94.1	1.32
Recom. Diet. Allow.	2200	57.0	1.10
C 1	1736	67.0	0.98
2	1508	62.2	0.76
3	2742	99.0	1.14
4	1724	82.3	0.99
5	1956	77.7	0.98
6	2398	90.8	1.34
7	1578	109.3	1.14
Mean	1949	84.0	1.05
Recom. Diet. Allow.	2300	60.0	1.15

[a] Based on recall of diet of preceding 24 hours; average for two days.

[b] Food and Nutrition Board, Nat. Acad. Sci. - Natl. Res. Council (1958), adjusted for desirable weight and age, assuming subjects are as active as the 25-year-old "reference" woman.

which supplied less than 2000 Cal./day. The diets of the subjects on the days of the recall records may have been atypical of their customary eating habits. The data suggest, however, that these women may be maintaining excess body weight on diets relatively low in energy value. Swanson et al. (1955) reported diets for a group of women which also indicated maintenance of overweight on limited food intakes.

Mean intakes of protein by all groups and mean intakes of thiamine by Groups A and B exceeded the recommended allowances for these nutrients. The thiamine of the diets of the overweight women averaged less than the recommended dietary allowance. In each case, the subjects whose diets supplied less than 2000 Calories per day had estimated thiamine intakes less than would be recommended on an individual basis.

Basal energy expenditure

Basal oxygen consumptions are shown in Table 16. Mean basal oxygen consumption for the young women of average weight was 9.42±0.42 l./hr. The mean value for the overweight young women exceeded that of the reference group by 1.00 l./hr.; for the underweight group this difference between means was 0.56 l./hr. Mean values for basal oxygen consumption were 8.86 ±0.33 and 10.42±0.69 l./hr., respectively, for the underweight and overweight groups. Ranges in basal oxygen consumption were 8.11 to 11.17, 8.18 to 13.24 and 7.81 to 10.30 l./hr., respectively, for the average, overweight and underweight

Table 16. Basal metabolism of subjects in three weight groups

Group and subject	Age	Body weight[a]		Height[a]	Basal oxygen consumption	Basal respiratory quotient	Basal metabolism		
		kg.	$kg.^{0.73}$				Cal./hr.	Cal./kg./hr.	$Cal./kg.^{0.73}$/hr.
	yrs.			cm.	l./hr.				
A 1	26	56.40	19.10	173.4	9.45	0.79	55.1	0.98	2.90
2	30	52.88	18.37	168.8	8.86	0.80	54.5	1.03	3.01
3	25	46.75	16.52	168.2	7.81	0.84	43.2	0.92	2.62
4	28	48.87	17.25	167.6	8.06	0.83	47.2	0.97	2.76
5	25	51.40	17.82	171.2	8.84	0.81	53.0	1.03	2.98
6	25	52.62	18.12	166.4	9.68	0.81	56.0	1.07	3.10
7	26	45.42	16.60	168.2	10.30	0.88	55.5	1.22	3.42
	26.4	50.62	17.68	169.1	8.86	0.82	52.1	1.03	2.97
	±0.7[b]	±1.45	±0.36	±0.9	±0.33		±1.8	±0.04	±0.10
B 1	34	60.12	20.12	168.2	11.17	0.89	65.9	1.10	3.31
2	29	51.26	17.86	165.5	9.91	0.79	55.1	1.08	3.12
3	32	65.88	21.24	173.8	10.60	0.78	63.0	0.96	2.96
4	25	59.32	19.90	163.3	8.11	0.80	49.0	0.82	2.48
5	32	48.82	16.97	155.4	9.45	0.81	51.1	1.04	2.99
6	31	52.40	18.06	158.0	8.35	0.78	53.2[c]	1.02	2.95
7	25	52.18	18.12	159.5	8.36	0.87	51.7	0.99	2.88
	29.7	55.71	18.90	163.4	9.42	0.82	55.6	1.00	2.96
	±1.3	±2.32	±0.58	±2.2	±0.45		±2.4	±0.04	±0.10

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[a] Average of two measurements, basal state.

[b] Mean and standard error.

[c] Based on one day only.

Table 16. (Continued)

Group and subject	Age	Body weight kg.	Body weight $kg.^{0.73}$	Height	Basal oxygen consumption	Basal respiratory quotient	Basal metabolism Cal./hr.	Basal metabolism Cal./kg./hr.	Basal metabolism $Cal./kg.^{0.73}$/hr.
	hrs.			cm.	l./hr.				
C 1	25	65.92	21.51	166.1	8.18	0.81	49.1	0.74	2.30
2	30	70.74	22.48	164.9	10.84	0.83	61.0	0.86	2.72
3	30	67.68	21.79	160.0	10.61	0.74	62.9	0.93	2.90
4	32	57.90	19.38	154.3	8.43	0.79	48.3	0.84	2.50
5	28	92.02	26.48	170.0	13.24	0.84	77.3	0.84	2.84
6	29	67.72	21.12	167.0	11.93	0.79	62.5	0.92	2.88
7	30	94.56	27.86	169.0	9.74	0.82	62.0	0.66	2.24
	29.1	73.79	22.95	164.5	10.42	0.80	60.4	0.83	2.63
	±0.8	±5.26	±1.16	±2.1	±0.69		±3.7	±0.04	±0.11

groups.

The respiratory quotients averaged 0.82 for the underweight and the average weight women and 0.80 for the overweight women. Five of the seven subjects in the average weight group had basal respiratory quotients below 0.82; the range for this group was from 0.78 to 0.89. The number of respiratory quotients below 0.82 was five for the overweight group and four for the underweight group. The ranges for these two groups were 0.74 to 0.84 and 0.79 to 0.88, respectively. Of a total of 21 young women, then, 14 subjects had respiratory quotients below 0.82, the value commonly accepted for apparently healthy adults on a mixed diet. The relatively high number of women with values below 0.82 suggests that there may be a higher proportion of fat in the diet of these subjects than would be assumed for a mixed diet yielding a respiratory quotient of 0.82. The mean non-protein respiratory quotients for Groups A, B and C were the same as the mean respiratory quotients. Differences between non-protein respiratory quotient and respiratory quotient, for individual subjects, were uniformly less than 0.02 except for one subject for whom the two values differed by 0.06. Hawthorne (1954) reported non-protein respiratory quotients of 0.83, 0.83 and 0.79, respectively, for underweight, average weight and overweight subjects. Among nine subjects studied by Kereluk (1956) were four overweight women with non-protein respiratory quotients ranging from 0.74 to 0.78.

Basal energy expenditures, expressed as Calories per hour, Calories per kilogram per hour and Calories per kilogram of body weight$^{0.73}$ per hour, also are presented in Table 16 for the subjects in the three weight groups. The means for the underweight, average weight and overweight women were 52.1±1.8, 55.6±2.4 and 60.4±3.7 Cal./hr., respectively. Analysis of variance indicated that the differences among groups were significant ($P \leq 0.05$). Thus the underweight group averaged 3.5 fewer Calories per hour and the overweight group averaged 4.8 more Calories per hour than the average weight group. The difference between the means of the underweight and overweight groups was 8.3 Cal./hr. Values for individual subjects ranged from 43 to 56 for Group A, 49 to 66 for Group B and 48 to 77 Cal./hr. for Group C, respectively.

Differences among basal energy expenditures for the three groups were statistically significant ($P \leq 0.01$) when values were expressed in terms of Calories per kilogram per hour and of Calories per kilogram$^{0.73}$ per hour. Mean basal metabolism values expressed as Calories per kilogram per hour were 1.03±0.04, 1.00±0.04 and 0.83±0.04, respectively, for the underweight, average weight and overweight groups. On the basis of Calories per kilogram$^{0.73}$ per hour, the mean basal energy expenditures were 2.97±0.10, 2.96±0.10 and 2.63±0.11, respectively. On the basis of body weight, then, differences between the underweight and average weight subjects were slight, but the overweight group had significantly lower basal energy expenditures.

Energy expenditure during physical activity

Energy expenditure values for the subjects in the three weight groups during resting and walking are given in Table 17. The experimental conditions were similar to those described for women in the study of age and energy expenditure. Each of the values represents the average of two observations made on different days. In Figure 3, the data are presented graphically.

Mean energy expenditures for resting were 61.0, 66.6 and 73.8 Cal./hr., respectively, for the underweight, average weight and overweight groups. Mean value for the underweight group was 5.6 Calories per hour less than that of the average weight group during resting; for the overweight group the mean value was 7.2 Cal./hr. more than that of the average weight group. The values were 8.9, 11.0 and 13.4 Cal./hr. more than the basal expenditures for these groups. That is, energy expenditure during resting was approximately 17, 20 and 23 per cent, respectively, above expenditure in the basal state.

Expressed as Calories per kilogram per hour, mean energy expenditure was 1.19 for the young women in Group A, the underweight group, 1.20 for the subjects in Group B, the

Table 17. Energy expenditures during walking of subjects in three weight groups

					Walking					
		Resting			2 m.p.h., 4% incline			3 m.p.h., 4% incline		
Weight group	Subject	Cal. /hr.	Cal./kg. /hr.	Cal. /kg$^{0.73}$ /hr.	Cal. /hr.	Cal./kg. /hr.	Cal. /kg$^{0.73}$ /hr.	Cal. /hr.	Cal./kg. /hr.	Cal. /kg$^{0.73}$ /hr.
A Underweight	1	65.5	1.15	3.61	178.1	3.13	9.32	223.3	3.93	11.69
	2	70.8	1.31	3.85	203.5	3.78	11.08	244.8	4.54	13.33
	3	43.1	0.92	2.61	123.8	2.66	7.50	163.0	3.50	9.87
	4	55.1	1.11	3.20	150.9	3.06	8.74	192.2	3.89	11.14
	5	67.5	1.31	3.78	173.2	3.35	9.72	213.5	4.12	11.97
	6	67.3	1.27	3.72	173.8	3.28	9.59	225.7	4.26	12.46
	7	57.3	1.23	3.46	195.8	4.17	11.80	219.9	4.68	13.24
		61.0 ±3.7[a]	1.19 ±0.05	3.46 ±0.16	171.3 ±10.2	3.35 ±0.19	9.68 ±0.53	211.8 ±10.1	4.13 ±0.15	11.96 ±0.45
B Average weight	1	74.9	1.23	3.72	224.8	3.68	11.17	244.0	4.00	12.12
	2	63.6	1.23	3.56	195.0	3.76	10.92	245.3	4.73	13.74
	3	74.7	1.14	3.52	233.1	3.54	10.98	273.3	4.16	12.87
	4	56.6	0.94	2.85	222.4	3.70	11.18	280.7	4.66	14.10
	5	63.9	1.32	3.77	150.4	3.11	8.86	203.0	4.20	11.96
	6	68.0	1.29	3.76	178.4	3.39	9.88	216.2	4.10	11.97
	7	64.7	1.22	3.58	226.8	4.28	12.51	290.4	5.42	16.02
		66.6 ±2.5	1.20 ±0.05	3.54 ±0.12	204.4 ±11.7	3.64 ±0.14	10.79 ±0.43	250.4 ±12.5	4.48 ±0.21	13.26 ±0.55

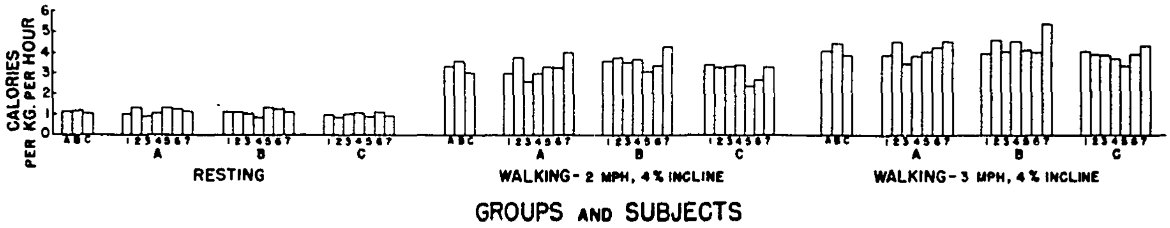
---

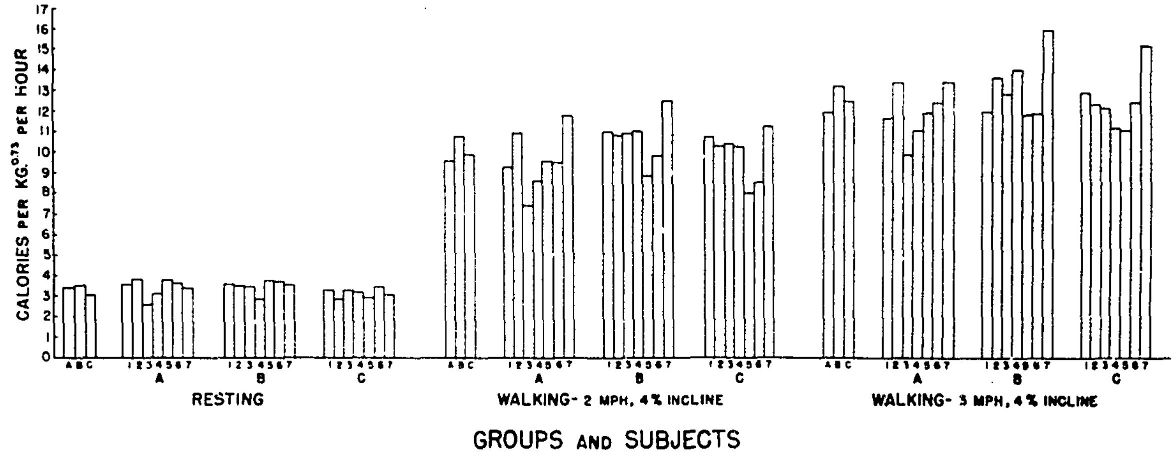
[a] Mean and standard error.

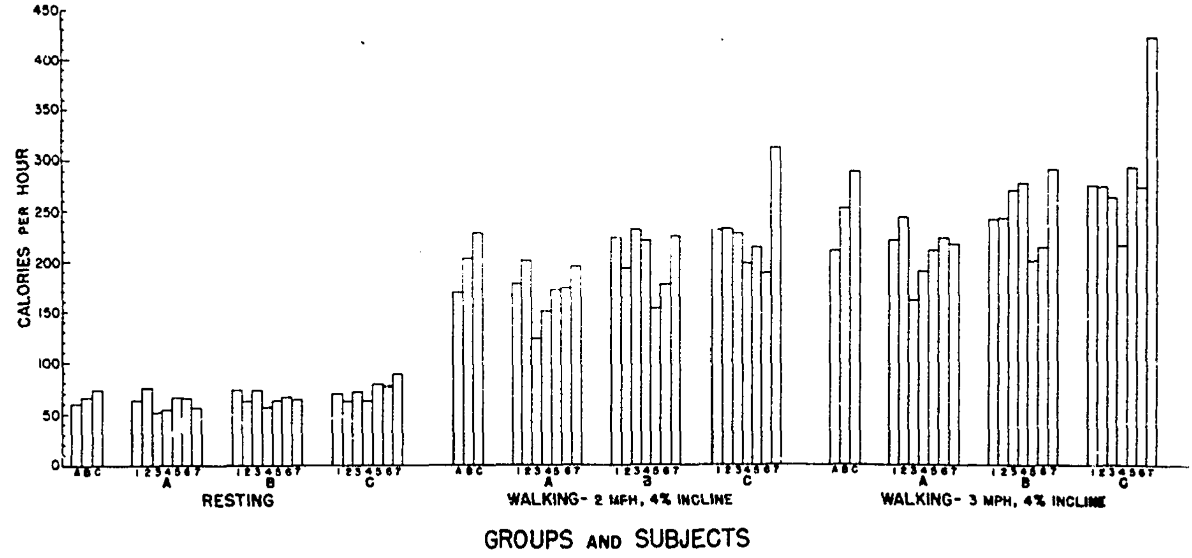
Table 17. (Continued)

					Walking					
		Resting			2 m.p.h., 4% incline			3 m.p.h., 4% incline		
Weight group	Subject	Cal. /hr.	Cal./kg. /hr.	Cal. /kg$^{0.73}$ /hr.	Cal. /hr.	Cal./kg. /hr.	Cal. /kg$^{0.73}$ /hr.	Cal. /hr.	Cal./kg. /hr.	Cal. /kg$^{0.73}$ /hr.
C Over-weight	1	70.3	1.05	3.26	231.3	3.46	10.76	277.9	4.16	12.92
	2	62.7	0.88	2.78	232.5	3.27	10.34	277.5	3.90	12.34
	3	72.8	1.07	3.34	228.1	3.34	10.46	265.9	3.90	12.20
	4	63.0	1.09	3.26	199.0	3.42	10.26	217.4	3.75	11.22
	5	80.0	0.90	3.02	215.1	2.42	8.12	294.8	3.32	11.13
	6	78.1	1.12	3.53	188.9	2.72	8.54	275.4	3.96	12.46
	7	90.0	0.94	3.22	312.4	3.28	11.21	424.0	4.44	15.22
		73.8	1.01	3.20	229.6	3.13	9.96	290.4	3.92	12.50
		±3.7	±0.04	±0.08	±15.2	±0.15	±0.43	±24.1	±0.13	±0.51

Figure 3. Variations in energy expenditure during walking tests by subjects in three weight groups expressed in three parameters


CALORIES PER KG. PER HOUR
0
1
2
3
4
5
6
ABC
1234567
A
1234567
B
1234567
C
RESTING
WALKING- 2 MPH, 4% INCLINE
WALKING- 3 MPH, 4% INCLINE
GROUPS AND SUBJECTS


CALORIES PER KG.$^{0.73}$ PER HOUR
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
ABC
1234567
A
1234567
B
1234567
C
RESTING
WALKING- 2 MPH, 4% INCLINE
WALKING- 3 MPH, 4% INCLINE
GROUPS AND SUBJECTS


CALORIES PER HOUR
0
50
100
150
200
250
300
350
400
450
ABC
1234567
A
1234567
B
1234567
C
RESTING
WALKING- 2 MPH, 4% INCLINE
WALKING- 3 MPH, 4% INCLINE
GROUPS AND SUBJECTS

reference group, and 1.01 for the overweight group, Group C. Corresponding values, expressed as Calories per kilogram$^{0.73}$ per hour, were 3.46, 3.54 and 3.20, respectively, for the three groups.

Apparently, resting energy expenditure increased with increase in weight when expenditure was expressed as Calories per hour: when expressed as Calories per kilogram per hour and per kilogram$^{0.73}$ per hour, it decreased with increase in weight for subjects who were overweight.

The differences among resting energy expenditures were statistically significant ($P \leq 0.01$) according to analysis of variance when values were expressed in each of the three parameters. Application of the Q-test indicated that the underweight women did not differ from the average weight women in energy expended during resting but that the overweight women differed significantly from both the women who were of average body weight and the women who were underweight.

Table 18 gives a comparison of the results obtained when energy expended during walking by women in the three weight groups was measured on two experimental days. Values are expressed as Calories per hour. During the second day the underweight group expended an average of 15 fewer Calories per hour at the two mile rate and five less Calories per hour at the three miles rate than on the first day. The overweight women had essentially the same energy expenditures when

Table 18. Comparison between days of mean energy expenditure during walking by women of different weights

Weight group	Number of subjects	Calories per hour 2 m.p.h., 4% incline Day 1	 Day 2	 3 m.p.h., 4% incline Day 1	 Day 2
Underweight	7	178.8±11.5[a]	163.7±9.5	214.4±11.1	209.1±10.2
Average weight	7	211.1±12.1	197.7±12.7	246.8±13.0	254.0±13.0
Overweight	7	229.1±19.8	230.2±14.7	285.4±27.2	295.4±22.3

[a] Standard error of the mean.

walking at two miles per hour on the two days but averaged 10 Cal./hr. more on the second day than the first when walking at three miles per hour. Since no uniform trend was manifested toward a reduction of energy expenditure on the second day of the experiment in comparison with the first day for the three groups, and since the same observation was made with the two groups of older women reported above, Groups D and E, values for the two test days were treated as replications for comparisons made among weight groups as well as among age groups.

During walking, mean energy expenditures were 171.3, 204.4 and 229.6 Cal./hr. at two miles per hour and 211.8, 250.4 and 290.4 Cal./hr. at three miles per hour, respectively, for Groups A, B and C (Table 17). Mean values for the underweight women, Group A, were less than those for the average weight group by 33.1 Cal./hr. at two miles per hour and by 38.6 Cal./hr. at three miles per hour. During walking the overweight women had mean energy expenditures that were greater than those of the average weight women by 25.2 Cal./hr. at two miles per hour and 40.0 Cal./hr. at three miles per hour. The differences among means were statistically significant ($P \leq 0.01$; analysis of variance) for intercomparisons of all three groups. The greatest expenditure of energy for an individual was 312.4 Cal./hr. at two miles per hour and 424.0 Cal./hr. at three miles per hour by subject 7C who weighed 94.56 kg. Subject 5C, however, who weighed 92.02 kg. expended less energy for walking at two miles per hour than seven women with smaller body weights; her energy expenditure for walking at three miles per hour exceeded that of other subjects who weighed less although there was only a small difference between values for her and for subject 7B who weighed only 52.18 kg.

The differences in energy expenditure among groups was eliminated in part by expression of Calories on the basis of body weight. Mean values on this basis were lower for the overweight women than for the other two groups. Although analysis of variance indicated that there was a difference among means, the Q test showed that only the mean difference between Groups B and C was significant when Calories per hour were expressed on the basis of body weight to the first power.

The parameter used to express metabolic body size, $W^{0.73}$, influenced total energy expenditure values for the groups with age as a variable factor in nearly the same manner as body weight to the first power. Subjects in those groups were estimated to be of desirable body weight for their height and frame. When this parameter was used for expression of energy expenditures of subjects of less and more than desirable body weight, total values for energy expenditure were affected differently than when reduced to Calories per kilogram of body weight. The lowest mean energy expenditure was by the underweight women. The mean value for the overweight group was less than that of the reference group but the differences were not statistically significant. On the basis of this parameter, the only difference between means which was statistically significant was the difference between the mean of the underweight subjects and that of the average weight subjects.

The mean increment in energy expenditure was calculated for each subject of the three weight groups in the same manner as was reported for subjects in the age groups. The energy cost of walking is given in Table 19 as the mean increment in hourly Calories and hourly Calories on the body weight basis for the three groups and the two walking speeds. Examination of the mean increments for the women of under-,

Table 19. Mean increment in energy expended during walking by subjects in three weight groups

		Rate					
		2 m.p.h, 4% incline			3 m.p.h., 4% incline		
Weight group	Number of subjects	Cal. /hr.	Cal. /kg. /hr.	Cal. /kg.$^{0.73}$ /hr.	Cal. /hr.	Cal. /kg. /hr.	Cal. /kg.$^{0.73}$ /hr.
Underweight	7	110	2.15	6.22	150	2.94	8.49
Average weight	7	138	2.56	7.25	184	3.28	9.72
Overweight	7	156	2.12	6.76	217	2.77	9.30

average and overweight yielded information similar to that obtained from the total heat production values during walking. The energy cost of movement of body weight on an incline of four per cent was indicated by the difference in the increment of 110 Cal./hr. for women averaging 50.6 kg. in weight and that of 156 Cal./hr. for women averaging 73.8 kg. in weight when walking at two miles per hour

The metabolic cost of walking was highest, on the basis of Calories per kilogram of body weight for women who were of desirable weight for their height and frame. Mean values at the two rates were 2.56 and 3.28 Cal./kg./hr. The differences in mean values between this group and those of the other two groups were not significant, however. The increment in energy expenditure for walking at two miles per hour was the same (2.15 and 2.12 Cal./kg./hr.) for the underweight and overweight subjects.

The increment in heat production, expressed on the basis of Calories per kilogram$^{0.73}$ per hour, reflected the same shift in relative energy expenditures that was observed for total energy expended during walking. Here also, the underweight women had the lowest increment in energy cost of walking of the three groups. The value for the underweight women was 6.22 Cal./kg.$^{0.73}$/hr. for walking at two miles per hour. The increased energy cost for walking at three miles per hour was 2.27 Cal./kg.$^{0.73}$/hr. greater, or 8.49 Cal./kg.$^{0.73}$/hr. The extra energy cost for walking three miles per hour as compared with two miles per hour averaged 2.47 Cal./kg.$^{0.73}$/hr. for the average weight women and 2.54 Cal./kg.$^{0.73}$/hr. for the overweight women.

These data indicated that movement and elevation of the body at moderate rates of speed at a slope of inclination of four per cent required expenditure of energy primarily for the movement of mass. That this energy cost of body movement can be charged against adipose tissue to a large extent is suggested by the observation that the energy cost of body movement expressed on the basis of the unit selected to express effective metabolic body size was essentially the same for women who were underweight as for those who were overweight.

Oxygen Debt Incurred During Walking

Values for total energy expenditure during walking presented in Tables 9 and 17 included the energy cost of recovery from oxygen debt as well as the observed expenditure of energy during walking. Oxygen debt, or the metabolic cost of recovery, was determined by subtracting the heat production during resting from the heat production during the recovery period; values were adjusted for the time of recovery. The oxygen debt was assumed to have accumulated over the entire fifteen minute period of the walking test; therefore the oxygen debt was calculated for the last five minute period of walking when the energy expenditure of walking was measured.

During the period of recovery from oxygen debt the subject was seated in a comfortable arm chair on a platform adjacent to the treadmill. This resting-after-walking period was terminated when the pulse rate of the subject approached or returned to the resting pulse rate which was recorded before walking. For most of the subjects this period was approximately 10 minutes in length although there was some variation among individual subjects.

Several observations were made of energy expenditure of subjects selected from each age and weight group during sitting after the initial resting period. Energy expenditure during sitting was comparable to that during resting, therefore it was assumed that oxygen debt could be measured after walking with the subject sitting while resting.

The energy expenditure calculated as the recovery from oxygen debt and expressed as Calories per five minutes, was 8.7, 13.0 and 16.0 at two miles per hour and 11.9, 14.8 and 20.1 at three miles per hour, respectively, for the underweight, average weight and overweight groups (Table 20). Comparable values for the young, middle age and older groups were

Table 20. Mean difference between energy expended during resting before and immediately after walking by five groups

Age range and group	Mean body weight[a] kg.	Metabolic cost of recovery after walking	
		2 miles per hour Cal./5 min.	3 miles per hour Cal./5 min.
25 to 34 yrs.			
Group A	51.08	8.7 (3.1-13.3)[b]	11.9 (7.2-28.0)
Group B	56.12	13.0 (2.8-26.3)	14.8 (2.2-25.4)
Group C	74.01	16.0 (6.6-35.4)	20.1 (7.0-39.5)
45 to 54 yrs.			
Group D	59.31	12.3 (5.8-23.0)	18.8 (7.5-47.8)
65 to 74 yrs.			
Group E	61.68	14.2 (9.1-19.2)	17.0 (3.5-29.0)

[a] Average of two measurements, immediately preceding walking tests.

[b] Range of values for group.

13.0, 12.3 and 14.2 at two miles per hour and 14.8, 18.8 and 17.0 at three miles per hour.

Wide variations among individuals for the metabolic cost of recovery appeared to be associated with variations in customary physical activity. Subjects who were known to walk for enjoyment or to and from work, and those who were considered to be active, physically, had lower recovery values than women who were only moderately active. Values for women in the seventh and eighth decades were similar to those of the women in the other two age groups. It is recognized that subjects in Group E were, to some extent, "select." Medical examinations and willingness to participate in the activities would eliminate many for whom this extent of physical activity would have been too strenuous.

Comparison of Two Methods for Determination of Basal Metabolism

Two methods for determination of basal metabolism were used in this study. Method I was based on measurement of carbon dioxide and oxygen exchange. Method II was carried out using a closed circuit apparatus. Values for both procedures were expressed in terms of energy expenditure.

Method I was used for determination of the values for basal metabolism which have been reported in Tables 8 and 16. Additional measurements of basal metabolism were made by Method II since the conditions of the study afforded an opportunity to evaluate this commonly used method for determining oxygen consumption.

Basal metabolisms obtained by the two methods are presented in Table 21. Calculations based on percent deviation of the values for the individual subjects showed that results obtained with Method II agreed with those of Method I by 5.6 per cent. In Method I, measurement of both carbon dioxide production and oxygen consumption provided bases for estimation of the respiratory quotient at the time of the test. Basal heat production, as determined clinically, is estimated from the caloric equivalent of oxygen at a respiratory quotient of 0.82. The 35 respiratory quotients presented in Tables 8 and 16 included one value for 0.82 (for subject 7C), 17 values that were less than 0.82 and 17 values that were more than 0.82. For 16 subjects, agreement between the two methods would have been closer had the determined respiratory quotient been used in calculation of the caloric equivalent of the oxygen consumption determined by the closed circuit technique. However, for 18 subjects the agreement would not have been better had the determined respiratory quotient been used. Therefore the differences in values for the two methods apparently resulted from some factor in addition to the use of an assumed respiratory quotient in the clinical procedure.

Table 21. Comparison of two methods for determination of basal metabolism

Group and subject	Age, yrs.	Body wt., kg.	Basal metabolism in Cal./hr. I. Gaseous exchange	Basal metabolism in Cal./hr. II. Clinical proc.
A 1	26	56.40	55.10	56.95
2	30	52.88	54.54	53.62
3	25	46.75	43.25	40.17
4	28	48.87	47.21	40.79
5	25	51.40	52.97	46.99
6	25	52.62	55.96	50.22
7	26	45.42	55.48	46.19
B 1	34	60.12	65.90	60.64
2	29	51.26	55.12	49.73
3	32	65.88	63.00	57.72
4	25	59.32	48.96	47.94
5	32	48.82	51.14	45.44
6	31	52.40	53.25[a]	51.20
7	25	52.18	51.70	52.27
C 1	25	65.92	49.12	54.10
2	30	70.74	61.01	58.59
3	30	67.68	62.90	63.84
4	32	57.90	48.32	46.84
5	28	92.02	77.29	71.71
6	29	67.72	62.46	61.69
7	30	94.56	62.05	68.65
D 1	47	70.24	58.02	56.24
2	47	55.44	43.87	49.23
3	52	58.26	61.40[a]	52.77
4	51	50.34	46.34	39.99
5	45	60.70	61.11	54.05
6	54	49.67	49.70	41.80
7	50	64.92	55.60	58.72
E 1	69	56.56	48.15	52.19
2	70	68.57	43.28	39.70
3	71	55.82	50.46[a]	46.96
4	67	59.90	53.92	46.50
5	70	63.32	54.94	45.68
6	74	57.56	47.82	44.20
7	65	66.17	55.64	55.81
Mean			54.49	51.69

[a] Based on one day only.

Energy Expenditure During a Modified Stepping Test

Measurements of energy expenditure of women stepping at a constant rhythm on a two-step platform were made in this laboratory before a treadmill was available. Only five subjects in all were studied. The subjects were selected at random and were not representative of a defined population. Although the inadequacy of the sample was recognized, the data were considered to be of interest since the work performed by these subjects involved more lifting of body weight than the work done on the treadmill. Therefore the data are presented here.

Subjects

The ages, heights, body weights and estimated desirable body weights of the subjects are given in Table 22. Ages varied from 16 to 43 years. The range in height was 162.2 to 167.5 cm. Body weights ranged from 52.48 to 77.47 kg. The group included one underweight subject (2S), one overweight subject (5S) and three subjects of desirable weight (1S, 3S and 4S).

Food recall records

Food intake records were obtained by dietary recall for two 24-hour periods. The mean energy value and protein and thiamine content of the diets were estimated by dietary calculations and are given in Table 22 along with the estimated

Table 22. Energy value and protein and thiamine content of diets[a] of subjects participating in stepping test

Subject	Age	Body weight[b]		Height[b]	Value of recall diets			Estimated allowances[d]		
		Observed	Desired[c]		Calories	Protein	Thiamine	Calories	Protein	Thiamine
	yrs.	kg.	kg.	cm.		gm.	mg.		gm.	mg.
1S	43	52.48	56.82	164.3	2940	138.0	1.16	2100	57	1.05
2S	16	55.12	61.82	167.5	1859	111.5	1.16	2400	62	1.19
3S	24	62.53	60.00	163.9	1856	95.8	1.43	2300	60	1.16
4S	31	65.22	60.91	162.2	1961	90.0	1.17	2300	61	1.15
5S	20	77.47	60.00	163.0	1318	59.9	0.65	2300	60	1.16

[a] Based on recall of diet of preceding 24 hours, average of two days.

[b] Average of two measurements, immediately preceding stepping tests.

[c] Based upon Metropolitan Life Insurance Company tables (1959) and subjective appraisal.

[d] Food and Nutrition Board, National Research Council (1958), adjusted for desirable weight and age, assuming subjects are as active as the 25-year-old "reference" woman.

dietary allowances which would be recommended for the individuals according to the Food and Nutrition Board (Nat. Acad. Sci. - Nat. Res. Council, 1958). The mean energy values of the two-day diets ranged from 1318 to 2840 Calories per day for the five subjects. The ranges for the protein and thiamine content were 59.9 - 138.0 gm. and 0.65 - 1.43 mg. per day, respectively. The caloric values of the recall diets were below the estimated allowances for all subjects except for one, Subject 1S, whose calculated intake exceeded her estimated allowance by 840 Calories. This subject considered that the two days for her recall diets were atypical. With the exception of the values for Subject 5S, the recall diets indicated liberal intakes of protein, and thiamine intakes which compared favorably with the estimated allowances. The low value of 1318 Calories per day for the diets of Subject 5S could be explained by her comments to the effect that she was on a self-imposed "reducing diet" during the time of the study. Apparently the food intake was restricted in such a way that the thiamine content of the diet was affected as well as the energy value although the diet supplied adequate protein.

Energy expenditure during activity

The values for energy expenditures for the subjects at rest and during stepping are shown in Table 23. The subjects

Table 23. Energy expenditure during stepping

			Day 1			Day 2			Day 1			Day 2		
				Stepping			Stepping			Stepping			Stepping	
Subject	Age	Body weight[a]	Resting	0-4 min.	4-8 min.	Resting	0-4 min.	4-8 min.	Resting	0-4 min.	4-8 min.	Resting	0-4 min.	4-8 min.
	yrs.	kg.	Cal./min.			Cal./min.			Cal./kg.$^{0.73}$/min.			Cal./kg.$^{0.73}$/min.		
1S	43	52.48	1.1	5.5	6.0	1.1	4.7	6.1	0.06	0.30	0.33	0.06	0.26	0.34
2S	16	55.12	1.2	5.9	6.9	1.1	6.2	7.5	0.06	0.31	0.37	0.06	0.34	0.40
3S	24	62.53	1.1	6.4	7.3	1.0	5.0	6.2	0.05	0.31	0.36	0.05	0.27	0.30
4S	31	65.22	0.9	12.5	4.7	0.9	8.2	9.1	0.04	0.59	0.22	0.04	0.39	0.43
5S	20	77.47	1.0	6.8	9.2	1.0	6.5	11.0	0.04	0.28	0.38	0.04	0.27	0.46

[a] Average of two measurements, immediately preceding stepping tests.

have been numbered in the order of increasing weight. The oxygen consumption was measured for two consecutive four minute periods (0 - 4 min.; 4 - 8 min.) of stepping. Recovery from oxygen debt was calculated by the same method that was used for arriving at oxygen debt for the subjects who participated in the walking tests. The metabolic cost of recovery from oxygen debt for the five subjects ranged from 0.22 to 0.69 Cal./min.

Energy expenditures during resting were similar for the five subjects. Ranges were 0.9 - 1.2 Cal./min. and 0.4 - 0.6 Cal./kg$^{0.73}$/min. These values extrapolated to an hourly basis were comparable to the resting energy expenditures of the subjects described in the preceding section. Values for energy expended during stepping were higher in the second four-minute period of the test than in the first period except in one instance. For subject 4S the value for the second period of the test exceeded the first by 0.9 Cal./min. on the second day of the experiment, but on the first day the total energy expenditures were 12.5 Cal./min. for the first four minutes and 4.7 Cal./min. for the second four minutes. No notations were made which would account for this atypical finding. Subject 5S had higher values for the second four minutes of stepping than for the first four minutes on both test days but the increment was greater than for the other subjects. This subject was overweight and the higher increment in energy expenditure during the second four minutes probably reflected the greater work load for the subject in comparison with the other subjects.

Heat production for Day 1 and Day 2 during the second four-minute stepping period averaged 7.2 Cal./min. for the underweight subject (2S), 10.1 Cal./min. for the overweight subject (5S) and 6.8 and 6.9 Cal./min., respectively, for two subjects of desirable body weight (3S and 4S). Subject 1S who had the smallest body weight of the group was considered also to be of desirable body weight; her energy expenditure averaged 6.0 Cal./min. for the second four-minute period on the two days.

When the data were expressed on the basis of metabolically effective body size, energy expenditures were similar for subjects 1S, 3S and 4S. Values were 0.34, 0.33 and 0.33 Cal. /kg$^{0.73}$/min., respectively, for the average of the last four-minute periods of the two test days. The sixteen-year-old girl (2S) had an energy expenditure of 0.38 Cal./kg$^{0.73}$/min. The highest value, 0.42 Cal./kg$^{0.73}$/min., was that of the overweight subject, 5S. These values also were the average for the last four-minute periods of the two test days.

The step test was done at greater metabolic cost to the subjects than were the walking tests. The mean energy expenditure of subjects in Group B, with a mean weight of 55.71 kg., was 4.17 Cal./min. or 0.22 Cal./kg$^{0.73}$/min. for walking at three miles per hour; the mean energy expenditure for subjects in Group C, with a mean weight of 73.79 kg., was 4.84 Cal./min. or 0.21 Cal./$kg.^{0.73}$/min. for walking also at three miles per hour. The influence of body weight on the metabolic cost of stepping was apparent although there was not a uniform increase in energy expenditure during stepping with an increase in body weight. Differences between test periods and between test days tended to be as great as differences in energy expenditures for subjects who weighed 52 to 62 kg., respectively. The increase in energy expenditure associated with the movement of additional body weight was apparent for subject 4S on the second test day and for the heaviest subject, 5S, on both test days.

Corollary

Satisfactory comparison of the variations of a biochemical or physiological characteristic among individuals is dependent primarily on the adequacy of a unit or basis for expression of the characteristic. Energy expenditure, whether in the basal state or during physical activity represents a gross value when expressed as Calories per hour. In effect, the value is a summation of all of the components of energy expenditure and the net metabolizable energy of the daily diet of an individual must be equivalent to the total energy expenditure if the individual is to maintain energy balance.

For comparative studies of energy metabolism, however, expression of heat production or energy expenditure on the basis of $W^{0.73}$ provides a parameter for metabolically active size and in part, at least, reduces differences in height, total body weight, skinfold thicknesses and skeletal size among individuals.

When the influence of age on energy metabolism was evaluated, the findings indicated that the women, 65 to 74 years of age, had a mean basal metabolism that was significantly lower than the mean values of women who averaged 20 or 40 years younger. This difference was not reflected in the energy expenditure of the three groups during walking. It was recognized, however, that there were differences among the three groups that were associated with body weight even though all women were selected on the basis of apparently desirable body weight for their size. The means for Groups B, D and E were 55.71, 58.51 and 61.13 kg., respectively; mean body weights raised to the 0.73 power were 18.90, 19.67 and 20.26, respectively. Mean body weights raised to the 0.73 power were 17.68, 18.90 and 22.95 kg., respectively, for Groups A, B and C.

The average unit for $W_{kg.}^{0.73}$ for subjects of Group E was between that of Groups B and that of Group C, the overweight women. The range in values was from 19.04 to 22.12 for Group E; the corresponding range for subjects in Group C was 19.38

to 27.86. Values for individual subjects in Group B, *i.e.*, women of desirable body weight and 25 to 34 years of age, ranged only from 16.97 to 21.24.

The differences in mean energy expenditure of the women in Group E from those of Group B and those of Group C were, in Cal./kg.$^{0.73}$/hr.:

	Basal metabolism	Walking	
		2 m.p.h.	3 m.p.h.
B - E	0.44	0.59	0.57
D - E	0.24	0.28	0.49
C - E	0.11	-0.24	-0.19

This comparison indicates that the mean basal metabolism of women in the seventh and eighth decades compared closely with that of overweight women only 25 to 34 years of age. The energy expenditures during walking when expressed on the basis of metabolic size were, on the average, greater than those of overweight women who were 40 years younger but less than those of average weight women who were 20 years younger. Since the body component which varies with body weight is adipose tissue and since higher percentages of body fat have been reported for older women (Brožek, 1956), the need for further investigation of factors influencing energy metabolism along with measurements of body fat is indicated. In general, it would appear that age influences basal energy metabolism either through a reduction in the number of metabolizing cell units during aging or a reduction in the intensity of the metabolic processes. Adipose tissue contains a small fraction of metabolically active tissue. Thus excess body weight may influence energy expenditure through an increase in effective metabolic size and through the additional work load imposed on the body in its self-propulsion. The data from this study indicate that age alone does not influence the increment in energy expenditure above basal metabolism for physical activity if the influence of age is separated from that of the body weight which frequently increases as people become older.

SUMMARY

The influence of age and body weight on energy expenditure of women during standardized physical activity was investigated. Thirty-five apparently healthy women, selected according to age and weight, were subjects for treadmill walking at a four per cent incline and at speeds of two and three miles per hour. The subjects were distributed among five groups. One group was composed of young women, 25 to 34 years of age, who were of desirable body weight for their height. Two groups of women, also of desirable body weight, varied in age with successive mean increments of 20 years. Two groups of women represented variations of body weight, i.e., underweight and overweight; these subjects were from 25 to 34 years of age.

Energy expenditures were measured in the basal state, at bed-rest approximately one and one-half hours after the noon meal, and during walking on the treadmill. Methods of indirect calorimetry were used. Values were expressed as hourly Calories, hourly Calories per kilogram of body weight and per kilogram of body weight raised to the 0.73 power. $W_{Kg.}^{0.73}$ was used as a unit to express metabolically effective body size.

Women aged 65 to 74 years had a significantly lower basal heat production, expressed as Calories per hour, than young women. Differences among means for all three age groups were significant when values were expressed either on the basis of body weight or of body weight raised to the 0.73 power. Mean energy expenditures expressed in Calories per kilogram$^{0.73}$ of body weight per hour for the young, middle age and older groups were, respectively, 2.96±0.10, 2.76±0.11 and 2.52±0.09.

The energy expenditures during resting averaged 3.54±0.12, 3.25±0.76 and 2.82±0.09 Cal./kg$^{0.73}$/hr. for the young, middle age and older groups, respectively. This decrease in energy expenditure with age was significant. A decrease in total hourly Calories and in Calories per kilogram per hour with age also was significant.

There were no significant differences among age groups in the energy expended during walking. Mean values, in Calories per kilogram$^{0.73}$ per hour, were 10.79±0.43, 10.48±0.59 and 10.20±0.19 at two miles per hour and 13.26±0.55, 13.18±0.87 and 12.69±0.43 at three miles per hour, respectively, for the young, middle and older age groups. The mean increment in energy expenditure during walking over that during resting was calculated; there were no differences among means for the three age groups. Mean values for the increments were 7.25, 7.08 and 7.38 Cal./kg$^{0.73}$/hr. at two miles per hour and 9.72, 9.93 and 9.86 Cal./kg$^{0.73}$/hr. at three miles per hour, respectively, for the young, middle and older age groups.

Basal energy expenditures averaged 2.97±0.10, 2.96±0.10 and 2.63±0.11 Cal./kg$^{0.73}$/hr., for the underweight, average weight and overweight women, respectively. Corresponding values for energy expenditure in the resting state were 3.46±0.16, 3.54±0.12 and 3.20±0.08 Cal./kg$^{0.73}$/hr. The Q test indicated that the overweight women differed significantly from women who were underweight or who were of desirable body weight. The differences were apparent for energy expenditures expressed in terms of each of the three parameters. No significant differences were apparent between the underweight women and the women of average body weight in energy expenditures in the basal state or during resting.

Energy expenditures during walking were significantly different among the three weight groups when values were expressed as Calories per hour. Mean values, as Cal./kg$^{0.73}$ /hr. for the underweight, average weight and overweight women were 9.68±0.53, 10.79±0.43 and 9.96±0.43 for walking at two miles per hour and 11.96±0.45, 13.26±0.55 and 12.50±0.51 for walking at three miles per hour, respectively. These values differed significantly only between groups of underweight women and women of average body weight. When energy expenditures during walking were expressed on the basis of body weight to the first power, significant differences were apparent only between the groups of overweight women and women of average body weight. The influence of body weight on the energy cost, or increment in energy expenditure, of walking was similar to the influence of body weight on the total energy expended during walking.

Five women, ranging in age from 16 to 43 years, participated in a modified step test. A two-step platform was used and the subjects stepped at a constant rate for two consecutive four-minute periods. Mean energy expenditures during the last four minutes for two test days ranged from 7.2 Cal./min. for a subject weighing 52.12 kg. to 10.1 Cal./min. for a subject weighing 77.47 kg.

The experimental plan provided an opportunity to compare values for basal metabolism determined by measurement of gaseous exchange of the subjects with those obtained by a commonly used clinical procedure involving a closed circuit apparatus. The mean difference between values obtained by the two methods was 5.6 per cent for a group of 35 women.

The experimental findings indicated that, although basal metabolism decreased with advancing age, there was no apparent influence of age on the metabolic cost of activity. The metabolic cost of activity did vary, however, with the body weight of the subjects.

LITERATURE CITED

Armstrong, D. B., Dublin, L. I., Wheatley, G. and Marks, H. H.
1951 Obesity and its relation to health and disease.
J. Amer. Med. Assoc. 147: 1007-1014.

Aub, J. C. and DuBois, E. F.
1917 The basal metabolism of old men.
Arch. Int. Med. 19: 823-831.

Beaudoin, R., Van Itallie, T. B. and Mayer, J.
1953 Carbohydrate metabolism in "active" and "static" human obesity.
J. Clin. Nutr. 1: 91-99.

Benedict, F. G.
1924 Physical factors in predicting the basal metabolism of girls.
Proc. Amer. Phil. Soc. 63: 25-29.

________.
1928 Basal metabolism data on normal men and women (series 2) with some considerations on the use of prediction standards.
Amer. J. Physiol. 85: 607-620.

________.
1938 Vital energetics. A study in comparative basal metabolism.
Carnegie Inst. of Washington, Pub. No. 503.

________ and Carpenter, T. M.
1910 Metabolism and energy transformations of healthy man during rest.
Carnegie Inst. Washington, Pub. No. 126: 179-186.

________ and Emmes, L. E.
1915 A comparison of basal metabolism of normal men and women.
J. Biol. Chem. 20: 253-262.

________ and Murschhauser, H.
1915 Energy transformations during horizontal walking.
Carnegie Inst. Washington, Pub. No. 231.

________ and Parmeter, H. S.
1929 The energy metabolism of women while ascending and descending stairs.
Amer. J. Physiol. 84: 675-698.

Benjamin, H. R. and Weech, A. A.
1943 Basal heat production in relation to growth.
Amer. J. Dis. Child. 65: 1-35.

Boothby, W. M., Berkson, J., and Dunn, H. L.
1936 Studies of the energy metabolism of normal individuals: a standard for basal metabolism with a
nomogram for clinical application.
Amer. J. Physiol. 116: 468-484.

Bowes, A. deP. and Church, C. F.
1956 Food values of portions commonly used.
Philadelphia, Pa., Philadelphia Child Health Society,
8th ed., 110 pp.

Bransby, E. R., Daubney, G. G., and King, J.
1948 Comparison of results obtained by different methods
of individual dietary survey.
Brit. J. Nutr. 2: 89-110.

Brobeck, J. R.
1948 Regulation of energy exchange.
Ann. Rev. Physiol. 10: 315-328.

Brody, S.
1945 Bioenergetics and growth.
1st ed., New York, N. Y., Reinhold Publishing Corp.

Brožek, J.
1956 Physique and nutritional status of men.
In Brozek, J., ed. Body measurements in human nutrition. pp. 14-30. Detroit, Michigan, Wayne University Press.

Cannon, W. B.
1929 Organization for physiological homeostasis.
Physiol. Rev. 9: 399-431.

Carpenter, T. M.
1949 The historical development of metabolism studies.
J. Amer. Dietet. Assoc. 25: 837-841.

Christensen, I. L.
1949 Nutritional status and dietary requirements of
older women. III. The basal metabolism of 47 adult
women ranging in age from 32 to 76 years.
Unpublished M. S. Thesis, Ames, Iowa, Library, Iowa
State University of Science and Technology.

Consolazio, C. F., Johnson, R. C., and Marek, E.
1951 Metabolic methods. Clinical procedures in the study of metabolic functions.
St. Louis, Mo., The C. V. Mosby Company.

Davenport, C. F.
1923 Body build and its inheritance.
Carnegie Inst. of Washington, Pub. No. 329.

Douglas, C. G. and Haldane, J. S.
1912 The capacity of the air passages under varying physiological conditions.
J. Physiol. 45: 235-238.

Dreyer, G.
1920 The normal basal metabolism in man, and its relation to the size of the body and the age expressed in simple formulae.
Lancet 199: 289-291.

Dublin, L. I. and Lotka, A. J.
1937 Uses of the life table in vital statistics.
Amer. J. Pub. Health 27: 481-491.

DuBois, E. F.
1936 Basal metabolism in health and disease.
3rd ed., Philadelphia, Pa., Lea and Febiger.

________ and DuBois, D.
1916 Clinical calorimetry. X. A formula to estimate the the approximate surface area if height and weight be known.
Arch. Int. Med. 17: 863-871.

Durnin, J. V. G. A.
1959 The use of surface area and of body-weight as standards of reference in studies on human energy expenditure.
Brit. J. Nutr. 13: 68-71.

________, Blake, E. C., and Brockway, J. M.
1957 The energy expenditure and food intake of middle-aged Glasgow housewives and their adult daughters.
Brit. J. Nutr. 11: 85-94.

________ and Brockway, J. M.
1959 Determination of the total energy expenditure in man by indirect calorimetry: assessment of the accuracy of a modern technique.
Brit. J. Nutr. 13: 41-53.

———— and Weir, J. B. deV.
1954 Variations in the metabolic costs of standard activities.
J. Physiol. 125: 60P-61P.

Elbel, E. R. and Green, E. L.
1946 Pulse reactions to performing step-up exercise on benches of different heights.
Amer. J. Physiol. 145: 521-527.

Erickson, L. E., Simonson, E., Taylor, H. L., Alexander, H., and Keys, A.
1946 The energy cost of horizontal and grade walking on the motor-driven treadmill.
Amer. J. Physiol. 145: 391-401.

Ferres, H. M., Fox, R. H., and Lind, A. R.
1954 Individual variation in energy expenditure.
J. Physiol. 123: 74P-75P.

Ford, A. M. and Hellerstein, H. K.
1957 Energy cost of the Master two-step test.
J. Amer. Med. Assoc. 164: 1868-1874.

Galvão, B. E.
1948 Human heat production in relation to body weight and body surface. I. Inapplicability of the surface law on lean men of the tropical zone.
J. Appl. Physiol. 1: 385-394.

Gephart, F. C. and DuBois, E. F.
1916 Clinical calorimetry. XIII. Basal metabolism of normal adults with special reference to surface area.
Arch. Int. Med. 17: 902-914.

Grollman, A.
1930 Physiological variations in cardiac output in man. XI. Pulse rate, blood pressure, oxygen consumption, arterio-venous oxygen difference and cardiac output of man during normal nocturnal sleep.
Amer. J. Physiol. 95: 274-284.

Harris, J. A. and Benedict, F. G.
1919 A biometric study of basal metabolism in man.
Carnegie Inst. of Washington, Pub. No. 279.

Hawthorne, B. E.
1954 Metabolic patterns of a group of overweight, underweight and average weight women.
Unpublished Ph. D. Thesis. East Lansing, Mich., Library, Michigan State University.

________, Brewer, W. D., and Ohlson, M. A.
1956 Metabolic patterns of a group of overweight, underweight and average weight women.
J. Nutr. 60: 391-412.

Iliff, A., Duval, A. M., Kinsman, G. M., and Lewis, R. C.
1940 A study of the effect of altitude on basal metabolism.
J. Biol. Chem. 133: xlvii-xlviii.

Insull, W. J.
1954 Report of indirect calorimetry by new techniques: a description and evaluation.
United States Army, Fitzsimmons Army Hospital, Medical Nutrition Laboratory, Report No. 146.

Johnston, L. C. and Bernstein, L. M.
1955 Body composition and oxygen consumption of overweight, normal and underweight women.
J. Lab. Clin. Med. 45: 109-118.

Kereluk, D. B.
1956 Daily energy expenditures of adult women and the metabolic cost of certain activities.
Unpublished M. S. Thesis. East Lansing, Michigan, Library, Michigan State University.

Keys, A.
1950 Energy requirements of adults.
J. Amer. Med. Assoc. 142: 333-338.

________ and Brožek, J.
1953 Body fat in the adult man.
Physiol. Rev. 33: 245-325.

________, Brožek, J., Henschel, A., Mickelson, O., and Taylor, H. L.
1950 The biology of human starvation. 2 vols.
Minneapolis, Minn., University of Minnesota Press.

Kiśe, Y. and Ochi, T.
1934 Basal metabolism of old people.
J. Lab. and Clin. Med. 19: 1073-1079.

Kleiber, M.
1947 Body size and metabolic rate.
Physiol. Rev. 27: 511-541.

Kleitman, N.
1929 Sleep.
Physiol. Rev. 9: 624-665.

Kofrányi, E. and Michaelis, H. F.
1940 Ein tragbarer Apparat zur Bestimmung des Gastoffwechsels.
Arbeitphysiol. 11: 148-150.

Krogh, A.
1923 Determination of standard (basal) metabolism of patients by a recording apparatus.
Boston Med. Surg. J. 189: 313-317.

Leichsenring, J. M. and Wilson, E. D.
1951 Food composition tables for short method of dietary analysis (2nd revision).
J. Amer. Dietet. Assoc. 27: 386-389.

Leverton, R., Biester, M., Pesek, I., Burrill, L., Mangel, M., and Cederquist, D. C.
1957 Changes with age in basal metabolic rate of adult women.
Fed. Proc. 16: 390.

Lewis, R. C., Duval, A. M., and Iliff, A.
1943a Basal metabolism of normal boys and girls from two to twelve years old, inclusive.
Amer. J. Dis. Child. 65: 834-844.

________, ________, and ________.
1943b Basal metabolism of normal children from thirteen to fifteen years old, inclusive.
Amer. J. Dis. Child. 65: 845-857.

________, Iliff, A., and Duval, A. M.
1943c Further consideration of the effect of altitude on basal metabolism.
J. Nutr. 26: 175-185.

________, ________, ________, and Kinsman, G. M.
1943d The effect of change of altitude on the basal metabolism of human subjects.
J. Lab. Clin. Med. 28: 851-859.

Lusk, G.
1933 Clio medica.
New York, N. Y., Paul B. Hoeber, Inc.

________.
1921 The elements of the science of nutrition.
3rd ed., Philadelphia, Pa., W. B. Saunders Company.

McCollum, E. V.
1959 A history of nutrition.
1st ed., Boston, Mass., Houghton Mifflin Company.

________, Orent-Keiles, E., and Day, H. G.
1939 The newer knowledge of nutrition.
5th ed., New York, N. Y., The Macmillan Company.

Magnus-Levy, O.
1942 Basal metabolism in the same person after an interval of fifty years.
J. Amer. Med. Assoc. 118: 1369.

________ and Falk, E.
1899 Der Lungengaswechsel des Menschen in den verschiedenen Altersstufen.
Arch. f. Anat. u. Physiol. Suppl. 314, pp. 314-381.

Mahadeva, K., Passmore, R., and Woolf, B.
1953 Individual variations in the metabolic cost of standardized exercises: the effects of food, age, sex and race.
J. Physiol. 121: 225-231.

Margaria, R.
1938 Sulla fisiologia, e specialmente sul consumo energetico, della marcia e della corsa a varie velocità ed inclinazioni del terreno.
Atti dei Lincei, Series 6. 7: 299-368.

Mason, E. D.
1940 Effect of change of residence from temperate to tropical climate on basal metabolism, weight, pulse rate, blood pressure and mouth temperature of 21 English and American women.
Amer. J. Trop. Med. 20: 669-675.

________ and Benedict, F. G.
1934 Effect of sleep on human metabolism with particular reference to south Indian women.
Amer. J. Physiol. 108: 377-383.

Maynard, L. A.
1950 Evaluation of dietary survey methods.
Fed. Proc. 9: 598-601.

________.
1953 Dietary standards in the United States.
Nutr. Abstr. Rev. 23: 154.

Meeh, K.
1879 Oberflächenmessungen des menschlichen Körpers.
Ztsch. f. Biol. 15: 425-458.

Mendel, L. B.
1923 Nutrition: the chemistry of life.
1st ed., New Haven, Conn., Yale University Press.

Metheny, E. L., Brouha, L., Johnson, R. E., and Forbes, W. H.
1942 Some physiological responses of men and women to moderate and strenuous exercise; a comparative study.
Amer. J. Physiol. 137: 318-326.

Metropolitan Life Insurance Co.
1951 Desirable weights for women.
Metropolitan Life Insurance Bull. T5043. New York, N. Y., Metropolitan Life Insurance Co.

________.
1959 New weight standards for men and women.
Statist. Bull., v. 40. New York, N. Y., Metropolitan Life Insurance Co.

Miller, C. D., Wenkam, N. S., and Kimwra, A. M.
1957 Basal metabolism in the elderly. A study of Japanese men and women in Hawaii.
J. Amer. Dietet. Assoc. 33: 1259-1265.

Moore, N. S. and Shaw, C. R.
1951 Nutritional status survey, Groton Township, New York. V. Physical findings.
J. Amer. Dietet. Assoc. 27: 94-97.

Müller, E. A. and Franz, H.
1952 Energieverbrauchsmessungen bei beruflicher Arbeit mit einer verbesserten Respirations-Gashuhr.
Arbeitsphysiol. 14: 499-504.

Naldandov, O., Heller, V. G., Krause, E., and Purdy, D.
1938 Basal metabolism of Oklahoma men and children.
J. Nutr. 15: 23-26.

National Academy of Sciences - National Research Council.
1958 Recommended dietary allowances.
Food and Nutrition Board, Pub. 589, revised 1958.
Washington, D. C., National Academy of Sciences - National Research Council.

Ohlson, M. A., Biester, A., Brewer, W. D., Hawthorne, B. E., and Hutchinson, M. B.
1956 Anthropometry and nutritional status of adult women.
Human Biol. 28: 189-202.

Orr, J. B. and Kinloch, J. P.
1921 Note on the influence of diet on the energy expenditure in work.
J. Roy. Army Med. Cps. 36: 81-86.

________ and Leitch, I.
1938 The determination of the calorie requirements of man.
Nutr. Abstr. Rev. 7: 509-529.

Orsini, D. and Passmore, R.
1951 Energy expended carrying loads up and down stairs. Experiments using the Kofrányi-Michaelis calorimeter.
J. Physiol. 115: 95-100.

Passmore, R. and Durnin, J. V. G. A.
1955 Human energy expenditure.
Physiol. Rev. 35: 810-840.

________ and Thomson, J. G.
1950 Energy expenditure during stepping.
Brit. J. Soc. Med. 4: 234-237.

________, Thomson, J. G., and Warnock, G. M.
1952 Balance sheet of the estimation of energy intake and energy expenditure as measured by indirect calorimetry, using the Kofrányi-Michaelis calorimeter.
Brit. J. Nutr. 6: 253-264.

Peters, J. P. and van Slyke, D. D.
1932 Quantative clinical chemistry, Vol. II.
Baltimore, Md., The Williams and Wilkins Co.

Phiphard, E. F.
1960 The recommended allowances in assessing diets. Role in studies of individuals and groups.
J. Amer. Dietet. Assoc. 36: 37-41.

Quiring, D. P.
1951 West Indian and New Orleans Negro metabolism tests.
J. Nutr. 45: 443-449.

Robertson, J. D. and Reid, D. D.
1952 Standards for the basal metabolism of normal people in Britain.
Lancet 262: 940-943.

Robinson, S.
1942 Effect of body size upon energy exchange in work.
Amer. J. Physiol. 136: 363-368.

Rogers, E. C.
1939 Basal metabolism of Connecticut State College students.
J. Nutr. 18: 195-203.

Rubner, M.
1883 Ueber den Einfluss der Körpergrösse auf Stoff und Kraftwechsel.
Ztsch. f. Biol. 19: 535-570.

Sherman, H. C.
1943 The science of nutrition.
1st ed., New York, N. Y., Columbia University Press.

________.
1952 Chemistry of food and nutrition.
8th ed., New York, N. Y., The Macmillan Company.

Shock, N. W. and Yiengst, M. J.
1955 Age changes in basal respiratory measurements and metabolism in males.
J. Gerontol. 10: 31-40.

Sloan, A. W.
1959 A modified Harvard step-test for women.
J. Appl. Physiol. 14: 985-986.

Smith, H. M. and Doolittle, D. B.
1925 Energy expenditures of women during horizontal walking at different speeds.
J. Biol. Chem. 65: 665-676.

Snedecor, G. W.
1956 Statistical methods applied to experiments in agriculture and biology.
5th ed., Ames, Iowa, Iowa State College Press.

Spector, W. S., ed.
1956 Handbook of biological data.
Philadelphia, Pa., W. B. Saunders Company.

Steele, J. M., ed.
1954 Methods in metabolic research. Vol. 6.
Chicago, Ill., The Yearbook Publishers, Inc.

Swanson, P., Roberts, H., Willis, E., Pesek, I., and Mairs, P.
1955 Food intake and body weight of older women.
In Eppright, E. S., Swanson, P. and Iverson, C. A., eds. Weight control. pp. 80-96. Ames, Iowa, Iowa State College Press.

Swartz, V.
1929 Human energy cost of operating a vacuum cleaner at different speeds.
J. Home Econ. <u>21</u>: 439-446.

Swift, R. W. and French, C. E.
1954 Energy metabolism and nutrition.
New Brunswick, N. J., The Scarecrow Press.

Taylor, C. M., MacLeod, G., and Rose, M. S.
1956 Foundations of nutrition.
5th ed., New York, N. Y., The Macmillan Company.

Tilt, J. and Waters, C. F.
1935 A study of the basal metabolism and diet of normal young college women in Florida.
J. Nutr. <u>9</u>: 109-117.

Thompson, E. M., Cox, E. W., and Ridgway, A. M.
1948 The basal metabolism of two hundred and eighteen girls and young women of southern Arizona, fourteen to twenty-three years of age, inclusive.
J. Nutr. <u>36</u>: 507-517.

________, Staley, M. G., Kight, M. A., and Mayfield, M. E.
1959 The effect of high environmental temperature on basal metabolism and serum ascorbic acid concentration of women.
J. Nutr. <u>88</u>: 35-47.

Trulson, M., Hegsted, D. M., and Stare, F. J.
1949 New York State nutrition survey. 2. A one-day study of food intake of adults.
J. Amer. Dietet. Assoc. <u>25</u>: 669-676.

von Schelling, H.
1954 Mathematical deductions from empirical relations between metabolism, surface area and weight.
Ann. New York Acad. Sci. 56: 1143-1164.

Wakeham, G. and Hansen, L. O.
1932 The basal metabolic rate of vegetarians.
J. Biol. Chem. 97: 155-162.

Watt, B. K. and Merrill, A. L.
1950 Composition of foods - raw, processed, prepared.
Agriculture Handbook No. 8. Washington, D. C., U. S. Dept. of Agriculture.

Williams, R. J.
1956 Biochemical individuality.
New York, N. Y., John Wiley and Sons, Inc.

Young, C. M., Chalmers, F. W., Church, H. N., Clayton, M. M., Murphy, G. C., and Tucker, R. E.
1953 Subjects' estimation of food intake and calculated nutritive value of the diet.
J. Amer. Dietet. Assoc. 29: 1216-1220.

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APPENDIX

Table 24. Case histories of subjects participating in the walking tests

Subject	
1A	Age, 26 yrs.; wt., 56.40 kg.; ht., 173.4 cm.; pleurisy in 1948; appendectomy and removal of ovarian cyst, 1955; chronic pain, lower left side abdomen, 1957; menstruation regular, occasionally with acute cramps; thin during childhood; reached adult weight at age 13; "good appetite"; married, no children.
2A	Age, 30 yrs.; wt., 52.88 kg.; 168.8 cm.; history of good health; menstruation irregular, with occasional discomfort; thin during childhood and adolescence; fairly good appetite.
3A	Age, 25 yrs.; wt., 46.75 kg.; ht., 168.2 cms.; tonsillectomy, age 4; low basal metabolism during childhood, with thyroid medication for about 5 years; menstruation regular, usually severe, requiring medication; "was a chubby little girl"; underweight since late adolescence; married, no children.
4A	Age, 28 yrs.; wt., 48.67 kg.; ht., 167.6 cm.; tonsillectomy, 1938; frequent colds to age 21; pleurisy, 1940; recurrent asthma, 1936 to 1944; usually has hay fever during June, July and August; menstruation regular; thin during childhood and adolescence; consistent pattern of underweight, with irregularities during adolescence.
5A	Age, 25 yrs.; wt., 51.40 kg.; ht., 171.2 cm.; bronchitis throughout childhood; tonsillectomy, age 4; appendectomy, 1956; menstruation regular; thin as child and adolescent; "always been underweight"; diabetes in family.
6A	Age, 25 yrs.; wt., 52.62 kg.; ht., 166.4 cm.; allergic to ragweed since 1943; tonsillectomy, 1946; slight acne; menstruation regular; average weight, childhood and adolescence; underweight since 1955; married, no children.

Table 24. (Continued)

Subject	
7A	Age, 26 yrs.; wt., 45.42 kg.; ht., 168.2 cm.; occasional colds; tonsillectomy, 1935; menarche at age 16; menstruation irregular; consistent pattern of underweight; married, no children.
1B	Age, 34 yrs.; wt., 60.12 kg.; ht., 168.2 cm.; occasional colds; menstruation regular; basal metabolism below standard since 1943; intermittent thyroid therapy, 1943 to 1946; average body weight, childhood, adolescence and adulthood; married, one child.
2B	Age, 29 yrs.; wt., 51.26 kg.; ht., 165.5 cm.; surgery for hernia in 1935 and for rectal fistula in 1955, 1956 and 1959; tonsillectomy and adenoidectomy, 1950; menstrual pattern regular; thin during childhood; body weight approximately 45 kg. from age 15 to age 22 when present weight was attained; married, no children.
3B	Age, 32 yrs.; wt., 65.88 kg.; ht., 173.8 cm.; history of good health; tonsillectomy, 1940; menstruation regular; plump during childhood; gains weight easily and makes conscious effort to maintain desirable weight; likes to walk and walks "more than most people."
4B	Age, 25 yrs.; wt., 59.32 kg.; ht., 163.3 cm.; history of good health; regular menstrual pattern except for some slight irregularity during past two years; normal weight pattern; maintains desirable weight "with diet and exercise."
5B	Age, 32 yrs.; wt., 48.82 kg.; ht., 155.4 cm.; good health; occasional colds; regular menstrual pattern; was "a plump little girl" and "a chubby teen-ager," amd makes conscious effort to maintain desirable weight; maximum weight attained since reaching adulthood, 54.5 kg.; has maintained present weight consistently for several years; only foreign-born subject in group; during past 10-year residence in United States has adopted American pattern of food intake.

Table 24. (Continued)

Subject	
6B	Age, 31 yrs.; wt., 52.40 kg.; ht., 158.0 cm.; good health; menstruation regular; body weight pattern consistently within desirable range; married, three children.
7B	Age, 25 yrs.; wt., 52.18 kg.; ht., 159.5 cm.; health good; menstruation regular; weight pattern consistently within desirable range.
1C	Age, 25 yrs.; wt., 65.92 kg.; ht., 166.1 cm.; occasional colds; allergic to corn and to ragweed pollen; menstruation regular within 25 to 30 day cycle; prior to birth of child, had 30 to 40 day cycle; "plump since the fourth grade"; married, one child, born prematurely.
2C	Age, 30 yrs.; wt., 70.74 kg.; ht., 164.9 cm.; tonsillectomy, 1939; menstruation regular, some discomfort with each period usually requiring medication; basal metabolism tests at age 17 indicated below normal rate; from age 17 has taken 1 grain thyroid daily under constant medical supervision, basal metabolism measured frequently, maintained within range of standard; consistent pattern of overweight since late childhood; maximum weight attained prior to age 22 was approximately 86 kg.
3C	Age, 30 yrs.; wt., 67.68 kg.; ht., 160.0 cm.; tonsillectomy, 1945; acute nephritis preceded by high blood pressure, 1946; menstruation regular but accompanied by discomfort requiring medication; has had five miscarriages since marriage in 1952; desirable weight during childhood; overweight during adolescence and adulthood with maximum of 77 kg.; is maintaining present weight by "counting calories."
4C	Age, 32; wt., 57.90 kg.; ht., 154.3 cm.; occasional severe colds; tonsillectomy, 1943; appendectomy, 1956; menstruation regular; several basal metabolism determinations have indicated below standard values; intermittent thyroid medication for short periods during and immediately following college; ". . . in my twenties weight became a problem, and has been ever since."

Table 24. (Continued)

Subject	
5C	Age, 28 yrs.; wt., 92.02 kg.; ht., 170.0 cm.; no chest illnesses; no surgery except for ceasarean section at births of daughter and of twins; menstruation normal and regular; normal weight during childhood; consistent pattern of overweight since adolescence; ". . . during 1955-56, after the twins were born, my weight went up to 215 lbs.; all the girls in my family, and my mother, are overweight."
6C	Age, 29 yrs.; wt., 67.72 kg.; ht., 167.0 cm.; some sinusitis during winter months; tonsillectomy, 1932; appendectomy, 1951; menstruation normal and regular; basal metabolsim test during first year in college below standard and followed by thyroid medication for short time; "chubby school child;" since adolescence, weight has ranged between 61 and 76 kg., with frequent fluctuations; married, two children, one miscarriage.
7C	Age, 30 yrs.; wt., 94.56 kg.; ht., 169.0 cm.; good health, regular menstrual periods; overweight since age 10; during past 10 years, average weight approximately 86 kg., with a maximum of 108.6 kg. in 1958; ". . . have to count calories consistently;" married, four children.
1D	Age, 47 yrs.; wt., 70.24 kg.; ht., 174.0 cm.; excellent health; regular menstrual pattern with indications of entering menopausal period; average body weight during lifetime.
2D	Age, 47 yrs.; wt., 55.44 kg.; ht., 168.1 cm.; infrequent colds; mastoidectomy, 1932; tonsillectomy, 1933; hysterectomy, 1950; early menarche; menstrual pattern regular; metabolism tests in 1934 and 1955 gave values below standard; thin during childhood and adolescence; since attaining adulthood weight has ranged between 57 and 66 kg.; maintains present weight "by regulating food intake."

Table 24. (Continued)

Subject	
3D	Age, 52 yrs.; wt., 58.26 kg.; ht., 163.0 cm.; good health except for occasional colds; tonsillectomy, 1926; hemorrhoidectomy, 1945; hysterectomy and oophorectomy, 1947; "normal" weight pattern; married, no children.
4D	Age, 51 yrs.; wt., 50.34 kg.; ht., 145.2 cm.; good health; tonsillectomy, 1930; menstruation regular; thin during childhood and adolescence; adult weight pattern "normal;" married, one child.
5D	Age, 45 yrs.; wt., 60.70 kg.; ht., 166.0 cm.; good health; seldom has colds; pneumonia in 1918 and 1936; tonsillectomy and amygdalectomy, 1920; menstruation regular; average weight during lifetime.
6D	Age, 54 yrs.; wt., 49.67 kg.; ht., 153.5 cm.; tonsillectomy, 192; appendectomy, 1930; sinusotomy, 1939; menstrual pattern was regular and "fairly normal;" currently in latter part of menopausal period; low basal metabolism observed in 1947, some thyroid medication, under supervision, from 1947 to 1954; thin during childhood; weight slightly above average during adolescence; adult weight has been within range of desirable weight.
7D	Age, 50 yrs.; wt., 64.92 kg.; ht., 173.0 cm.; consistently good health history except for pneumonia in 1932; menstruation regular; low basal metabolism observed in 1948 and followed by short period of thyroid medication; thin during childhood and adolescence; adult body weight maintained within range of desirable weight.
1E	Age, 69 yrs.; wt., 56.56 kg.; 160.5 cm.; good health except for infrequent colds; pneumonia, 1958; tonsillectomy, 1938; surgery on right forearm following break of ulna, 1953; menstruation was regular; completed menopausal period, 1935-1937, with no irregularity or discomfort; has maintained desired weight consistently during adulthood.

Table 24. (Continued)

Subject	
2E	Age, 70 yrs.; wt., 62.57 kg.; ht., 165.5 cm.; infrequent colds; appendectomy and hysterectomy, 1929; tonsillectomy, 1935; menarche in 1912; irregular menstruation until 1914; weight history normal; married, one child.
3E	Age, 71 yrs.; wt., 55.82 kg.; 153.1 cm.; good health; no chest illnesses except pleurisy for five weeks in 1920; menstruation regular; menopause began at age 47, completed at age 49, with only slight discomfort; average weight during childhood and adolescence; adult weight has been consistently within desirable range; married, two children.
4E	Age, 67 yrs.; wt., 59.90 kg.; ht., 149.3 cm.; no chest illnesses other than lung infection, 1949 and 1951; appendectomy, 1918; tonsillectomy, 1932; regular menstrual periods; menopause completed with no difficulties at age 48; overweight during childhood; thin during adolescence and early adulthood; gained weight following menopause; currently weight fluctuates between 60 and 66 kg.; makes continuous efforts to attain and maintain desirable weight; married, three children.
5E	Age, 70 yrs.; wt., 63.32 kg.; ht., 169.6 cm.; appendectomy, 1913; tonsillectomy, 1916; "Malta fever," 1919; hemorrhoidectomy, 1930; allergic to ragweed pollen; late onset of menarche at age 16; menopause began at age 48, completed at age 50; thin during childhood and adolescence; has consistently maintained desirable weight during adulthood.
6E	Age, 74 yrs.; wt., 57.56 kg.; ht., 155.4 cm.; pneumonia with pleurisy several times during childhood; tonsillectomy, 1910; surgery for rectal fistula, 1927; menstruation regular; menopausal period from age 48 to age 50; slight tendency toward overweight during adolescence; weight pattern consistently within desirable range for rest of lifetime; married, one child.

Table 24. (Continued)

Subject	
7E	Age, 65 yrs.; wt., 66.17 kg.; ht., 165.8 cm.; regular menstrual pattern after first year when periods extended for 12 or 14 days; menopause entered in 1930, completed 1933-1934, without discomfort; slender during childhood and adolescence; adult weight pattern consistently within range of desirable weight.

Table 25. Instructions for basal metabolism tests

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1. The night before the test:

    a. Do not eat or drink anything after 10 p.m.

    b. Be sure to get at least 8 hours of sleep or bed rest.

2. The morning of the test:

    a. Do not do anything more than you have to do to get washed and dressed.

    b. You may clean your teeth and rinse your mouth with water but do not drink or swallow any water.

    c. Dress as slowly and simply as possible.

    d. Do not eat or drink anything.

    e. Do not make your bed or do anything about the house.

    f. Either sit or lie down relaxing until someone comes to take you to the college.

    g. Please note exact time urine is voided after arising.