PROBLEMS RELATED TO THE CALORIC COST OF LIVING*

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Introduction

The formation and breakdown of various metabolites and the associated energy transfers within the body are intimately reflected by the total oxidative process and can be adequately assessed on a total body basis by careful measurements of oxygen consumption. If body composition is unchanged on a given dietary regimen, it therefore follows that one can also assess the daily energy demands of the body by measuring daily energy intake. In the past, most assessments of daily energy needs were made on the basis of the energy content of ingested food, with the exception of the considerable number of calorimetric measurements which took place in the late 1800's and the early 1900's. Although dietary surveys and other intake techniques are useful procedures, assessment of caloric requirements from food intake assumes that intake = output. In many areas of the world, intake and output are not equal and problems such as emaciation result in calorically "under-privileged" countries and obesity in "privileged" countries.

Newer information has increased awareness that energy intake and expenditure are mutually complementary in the construction of scales of caloric need. In addition, intake and expenditure data have been supplemented by nitrogen and electrolyte balance and body composition studies. In this way caloric needs can be appraised more physiologically and precisely than has been possible from energy intake information alone. Recently a surge of activity has occurred in the field of indirect calorimetric measurement largely because lightweight portable instrumentation has been developed which enables the investigator to get "on the job" to measure the energy expenditure of the worker without marked alteration of the task by the measuring equip-

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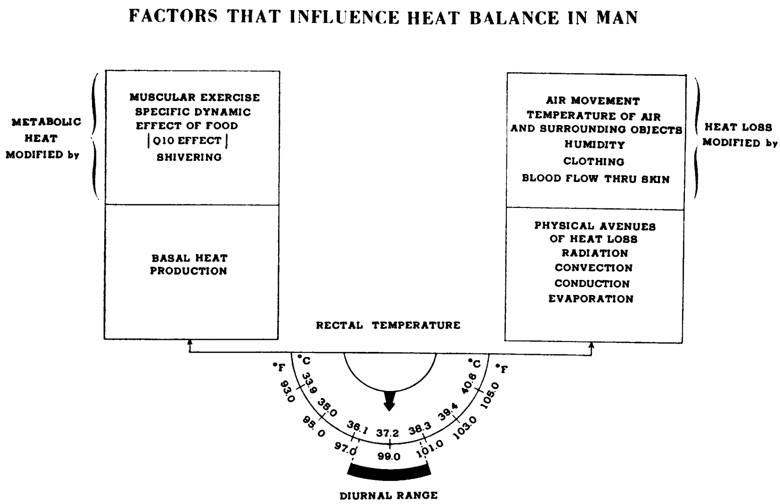


Reproduced through the courtesy of Buskirk, E. R. and Bass, D. E. *Science and Medicine of Exercise and Sports*, Harper & Bros. (To be published.)[4]

Fig. 1

The blackened area signifies the diurnal range in rectal temperature that may occur in a physically active individual.

ment. This boon should continue with the advent and utilization of new miniature equipment which will facilitate telemetering of information from the job site directly to the laboratory.

Several reviews have been prepared which provide detailed information about the caloric cost of various physical activities[1-3]. While these reviews provide considerable guidance, they do not provide complete information about the daily caloric requirements for a particular occupation. Since jobs change and recreational habits change and, indeed, man himself changes (man today is taller and heavier than his counterpart of 20 years ago), data on caloric requirements are usually somewhat dated. Thus, a continuing review of caloric needs is required.

In this presentation, an attempt at bringing our information "up-to-date" will not be undertaken, but rather, attention will be focused on some of the special problems related to the caloric cost of living, such as: 1) How do we spend our time? 2) What factors are important in altering the diurnal pattern of energy expenditure? 3) What are some of the newer methods of measuring energy expenditure? 4) Are caloric balance studies not feasible unless one has a calorimeter? 5) What attempts have been made to classify physical work and how can

TABLE I—COMPARISON OF TIMES SPENT PER 24 HOURS (h) LYING, SITTING AND STANDING BY PERSONS IN DIFFERENT OCCUPATIONS

Subjects and reference	*Lying* h	*Lying* min	*Sitting* h	*Sitting* min	*Standing* h	*Standing* min	*Total* h	*Total* min
Mine workers (Garry *et al.* 1955)	7	45	8	9	2	34	18	28
Clerks (Garry *et al.* 1955)	7	42	8	22	4	3	20	7
Cadets—first survey (Widdowson *et al.* 1954)	8	26	9	13	—	18½	17	57
Cadets—present survey	8	37	7	6	1	58	17	41
Schoolboys (Wiehl, 1944)	9	28	10	28	—	—	19	56
Factory workers* (Bransby, 1954)	8	34	5	11	—	21	14	6

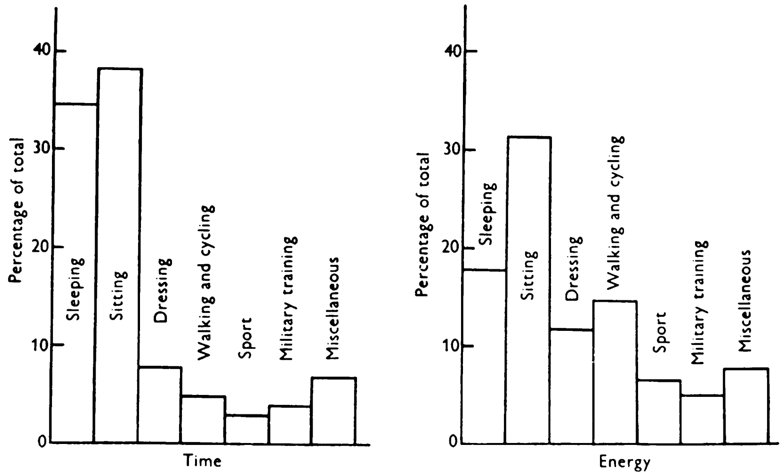
* Excluding working hours, which totaled 6 h 42 min/day.

Reproduced through the courtesy of Edholm, O. G. and Fletcher, J. G. *Brit. J. Nutr.* 9:286, 1955. (Cambridge University Press)[5]

these attempts be improved? Although partial answers to the above questions are attempted, treatment of each problem is fragmentary rather than comprehensive. Perhaps more questions are raised than answered, which further serves to emphasize our meager knowledge about the caloric cost of daily living in the modern age.

How do we spend our time? The factors that influence heat balance in man are shown in Figure 1[4]. If attention is confined to the heat production side of the scale, we find that metabolic heat production may be modified by muscular exercise, the "specific dynamic" effect of food, an increase in body temperature and shivering. Of these factors the importance of muscular exercise in increasing the daily heat production or metabolic rate is usually emphasized. When one exercises, energy expenditure can increase to 20 or more times the resting value; however, it is surmised that physical activities involving an increase above five-fold are rarely undertaken by the majority of men and women past the age of 25 or 30 years. But how active physically is the adult population at large? Fortunately, a few time-motion studies of certain occupations have been conducted, but little time-motion information is available, to the author's knowledge, for recreational activities.

As an example of industrial time-motion information, the summary table prepared by Edholm *et al.*[5] of times spent by various persons lying, sitting, and standing in various occupations is presented as Table I. From 17-20 hours per day are spent in resting positions, if Bransby's



Reproduced through the courtesy of Widdowson, E. M. *et. al. Brit. J. Nutr. 8*:148, Cambridge University Press[6], 1954.

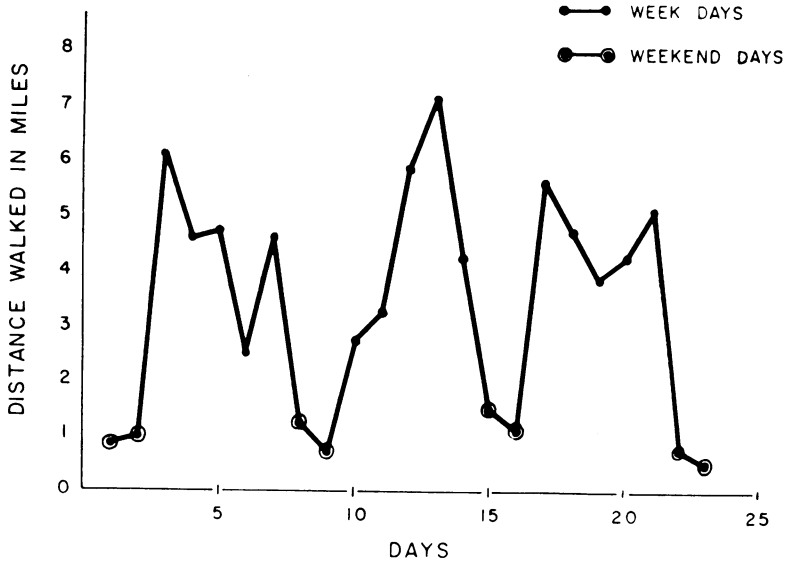
Fig. 2—Percentage of their time and energy which the cadets devoted to various occupations.

data for factory workers are omitted. (Presumably the factory workers spent part of the 6 hour 42 minute working period in a resting position, and the 14 hour total does not include this time.)

Although the major portion of the day may be spent in a resting position, how much of the daily caloric expenditure is associated with rest and how much with exercise? As an illustration, the data of Widdowson *et al.*[6] on British cadets are cited (Figure 2). Approximately 25 per cent of the cadets' time was spent participating in physical activity involving body movements, and approximately 45-50 per cent of the daily energy expenditure was associated with this activity. So far as young people are concerned, the British cadets studied by Widdowson are probably more active than the average student in the United States. An important point here is that little information of this kind is available in the U. S. literature; most of the above studies were British. An exception is the time-motion information obtained on soldiers from the United States and other nations while they participated in various military activities.* The data from soldiers, however, can only be applied in limited measure to the civilian population.

How constant is our energy expenditure from day to day? The daily energy expenditure for a given individual is not constant either

* Medical Nutrition Laboratory Reports, Fitzsimmons Army Hospital, Denver 8, Colorado.



Reproduced through the courtesy of Stunkard, A. J. *Psychosomatic Med.* 20:360, 1958.[7]

Fig. 3—(Patient A.A.) Variations in physical activity associated with the weekday-weekend cycle. On the ordinate are measured distances walked in miles, on the abscissa time in days. The circled points represent weekend days, the smaller points weekdays.

on a day to day or week to week basis. Probably the largest variation in weekly activity is produced by the weekend phenomenon.

Figure 3 was prepared by Stunkard[7] from pedometric data obtained from an obese subject who obviously "rested" each weekend and walked only a nominal number of miles (2.5 - 7.5 miles per day) during the work week. This active weekday, restful weekend activity pattern is one extreme; the other is provided by the individual who rushes home each Friday afternoon, dons his working or sporting clothes and proceeds to garden, rebuild the house or recreate all weekend. For this individual, energy expenditure may triple on weekends with respect to the work week. Most of us fall somewhere between these extremes. It would be an important contribution if daily, weekly and even seasonal frequency distributions could be established for the various energy expenditure patterns.

Several studies have been reported in which the daily energy expenditure by the obese individual has been less than that of his lean counterpart[8-10]. An example is provided by Table II, which shows a comparison of the daily and weekly walking distances traversed by

TABLE II—DISTANCES WALKED BY OBESE AND NONOBESE WOMEN* (MILES)

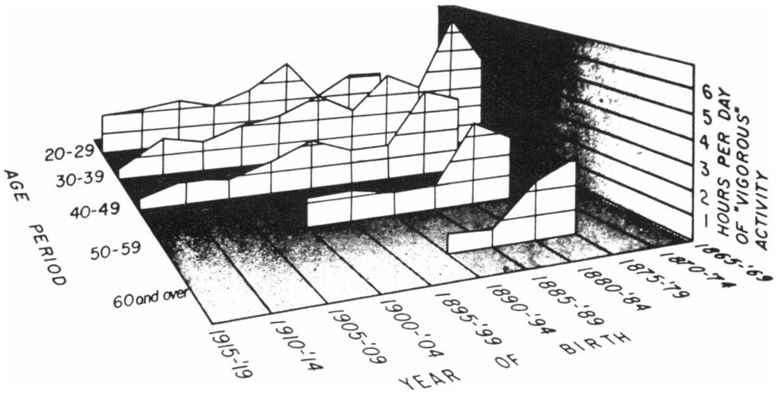
Weekly Distances			*Daily Distances*	
Obese	*Nonobese*	*Difference*	*Obese*	*Nonobese*
10.0	28.5	—18.5		4.0 ± 1.0
23.0	17.5	+ 5.5	3.3 ± 0.8	2.5 ± 1.7
11.0	19.5	— 8.5	1.6 ± 0.7	
16.5	34.0	—17.5	2.4 ± 0.5	
8.0	22.8	—14.8		3.3 ± 1.8
7.8	16.5	— 8.7	1.2 ± 0.4	2.4 ± 0.3
12.0	39.5	—27.5		5.6 ± 2.4
10.7	23.0	—12.3	1.5 ± 0.5	
24.0	31.4	— 7.4		
8.3	30.5	—21.2	1.2 ± 0.4	4.4 ± 2.3
5.5	64.5	—59.5		
10.0	38.7	—28.7		
10.2	61.7	—51.5		8.8 ± 1.2
31.0	35.0	— 4.0		5.0 ± 1.5
Total				
14.4 ± 7.6	34.3 ± 14.5	—20.0 ± 16.2	1.8 ± 0.9	4.5 ± 2.5
		Significant at the 1% level.		

* The obese and nonobese women were matched for age and occupation. Distances walked were measured with pedometers.

Reproduced through the courtesy of Dorris, R. J. and Stunkard, A. J. *Amer. J. med. Sci. 233*:622, 1957.[8]

obese and non-obese women matched for age and occupation. On an average, the non-obese women walked more than twice as many miles per unit time as the obese. It should be emphasized that even the non-obese women did not walk extensively each day—two of the non-obese women averaged less than three miles per day[8].

How does our energy expenditure today compare to what it might have been 20 or more years ago? Recent information gathered from a questionnaire survey of Michigan State graduates suggests that a distinct decrease in physical activity has taken place[11]. Figure 4 shows a comparison of the estimated hours per day of "vigorous" activity obtained at several age levels. There seems to have been a decrease in physical activity through the years at all age levels. It is realized that this observation may be colored by nostalgic heightening of the degree of vigor with which activities were pursued earlier in life and recalled later.



Reproduced through the courtesy of Montoye, H. J. *et al.* *Longevity and morbidity of college athletes,* Phi Epsilon Kappa Fraternity, Indianapolis, Ind., 1957.[11]

Fig. 4—Comparison of subjects born in different years regarding hours per day of vigorous activity during various periods of life.

Diurnal variation in energy expenditure: No matter what the occupation of an individual, there are usually days when only a minimum of physical activity is undertaken. On these days the sequence of events may go something like this: sleep, arise, wash, shave, etc., breakfast, read, lunch, watch television, dine, watch television and retire. For people who are not bedridden, a similar schedule represents what might be called a "baseline" diurnal energy expenditure pattern. Of course many patterns exist depending on the habitual schedule for a given individual. Some of the factors which influence the diurnal pattern are discussed below.

(a) *Sleep:* In general, average energy expenditure for the night hours by many people approximately equals basal metabolic rate; it is oversimplification, however, to state this as categorical truth for all people, or for all nights for the same person. The energy expenditure associated with sleep is not constant; it varies hour by hour during the night and may vary considerably between nights in the same individual. This variation is associated with changes in the depth of sleep, body movements during sleep, the amount and kind of food eaten before retiring, and the environment in which sleep is attempted. Figure 5 shows the change in oxygen consumption during the night in four young adult males. Two of these subjects followed a consistent trend each night they were observed; however, two other subjects demonstrated oxygen consumption patterns that were quite variable from night to night[12].

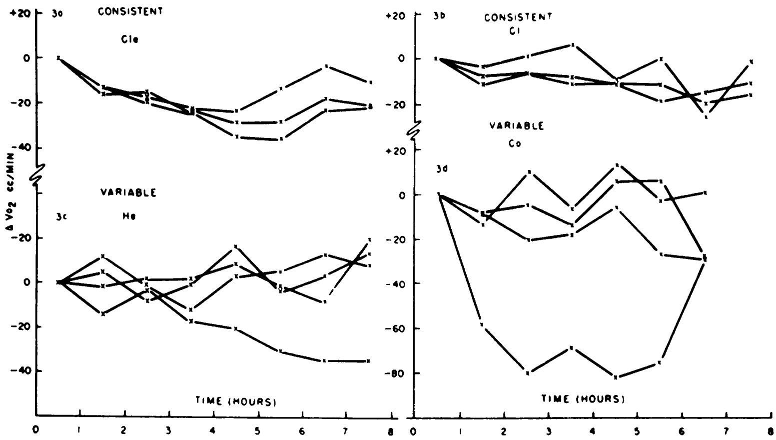


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Fig. 5—Intra-individual variation in pattern of O_2 consumption (Vo_2) throughout the night; *a* and *b* show examples of consistency while *c* and *d* show variability.

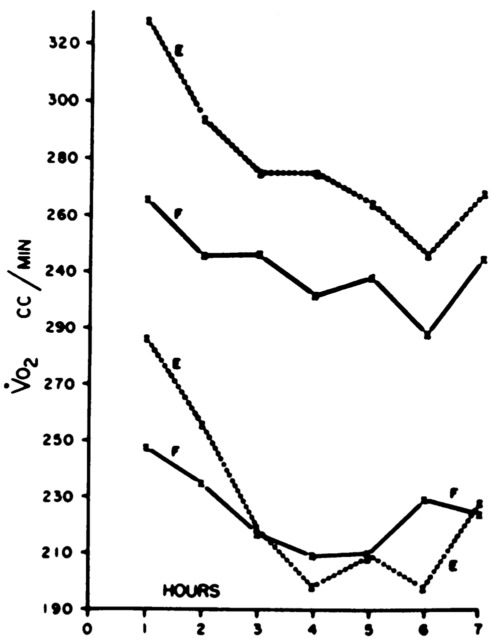

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Fig. 6—Oxygen consumption (Vo_2) of two men sleeping in arctic bags in —30 F air. Each curve represents six man nights.

E—Oxygen consumption after eating; meal fed immediately before retiring.

F—Fasting: last meal fed 5-6 hours before retiring.

TABLE III—HEAT PRODUCED DURING SLEEP (1 A.M. TO 7 A.M.) FOLLOWING DIFFERENT CONDITIONS OF ACTIVITY, AS REPORTED BY BENEDICT AND CARPENTER* (AVERAGE PER HOUR)

Subject	*Sleep after rest* cals.	*Sleep after moderate work* cals.	*Sleep after severe work* cals.	*Sleep after very severe work* cals.
E.O.	69.3	74.8	—	—
J.F.S.	60.4	65.3	—	—
J.C.W.	77.2	—	83.1	—
B.F.D.	69.8	—	83.3	—
A.L.L	78.3	—	83.7	97.9

* All work ceased at least 7 hours before metabolism measurements began except in the case of very severe work in which work ceased but 1 hour before.

Original data recorded in: Benedict, F. G. and Carpenter, T. M., Carnegie Institution of Washington. Publication No. 126, 1910.
Reproduced through the courtesy of Edwards, H. T. *et al.* *New Engl. J. Med.*, Sept. 12, 1935.[15]

Although divergent patterns of energy expenditure during the night may also be shown by individuals regarded as consistent sleepers, others have also found that a rough classification of sleeping patterns is possible. Kleitman[13], for example, has found it convenient to divide adults into three groups according to the manner in which they rest:

1. absolute rest throughout the night
2. three hours of absolute rest followed by periods of relative and absolute rest
3. many periods of relative rest

If a continuous record of oxygen consumption is obtained for the night hours, one finds that physical activity can readily be discerned by an elevation in oxygen consumption.

Eating immediately before retiring may increase metabolic rate during the first few hours after retiring and may in certain individuals be associated with a higher than normal metabolic rate during the night[14]. This is shown in Figure 6.

If strenuous physical activity is undertaken during the day, energy expenditure during night hours may be elevated considerably. Table III shows results obtained by Benedict and Carpenter as reported by Edwards *et al.*[15] on several subjects after they had been subjected to work loads varying in severity. There seems to be a direct relationship be-

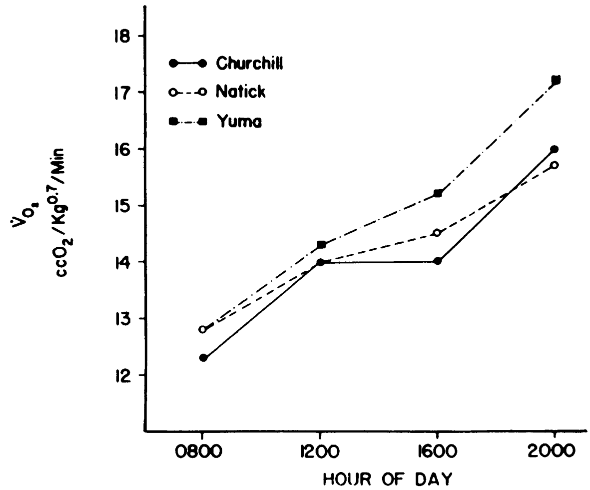

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Fig. 7—Change in resting oxygen consumption (Vo_2) throughout the day in three different climates which were respectively: Churchill, cold, winter; Natick, temperate, fall; Yuma, hot, dry, summer.

tween the severity of work performed during the day and the energy expenditure during sleep, even when the metabolic rate was measured several hours after work had ceased and the individual had retired.

(b) *Food:* In a recent series of experiments conducted on young adult male personnel in military service, it was concluded that the major factor affecting *resting* energy expenditure during the day was the "specific dynamic action" (SDA) of food[16]. Food exerted a greater effect on *resting* metabolism than either moderate physical exercise or the natural environment. Figure 7 shows the elevation in resting oxygen consumption that routinely occurred when three meals per day were eaten. The values plotted are mean values for eight men and were recorded after 30 minutes' rest just prior to eating the regular meal. No effect of natural climate could be observed (no difference between curves), although the men were outdoors continuously between meals and measurements in each climate. Only the later stages of the typical SDA curve after each meal are represented by each point plotted in Figure 7, which may be somewhat misleading unless a continuous curve of Vo_2 during the daytime hours is presented as a reference. This reference is provided by Figure 8, which shows oxygen consumption values obtained at 20-minute intervals throughout the day in one individual[16].

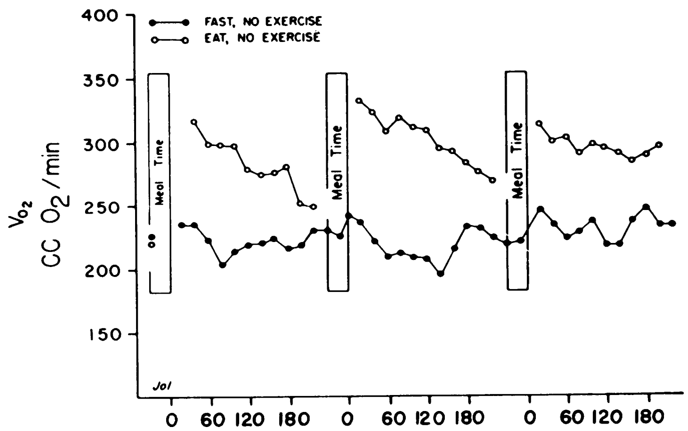

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Fig. 8—Variation in resting oxygen consumption (V_{O_2}) throughout the day when food was varied. Abscissa—Time in min. after meal.

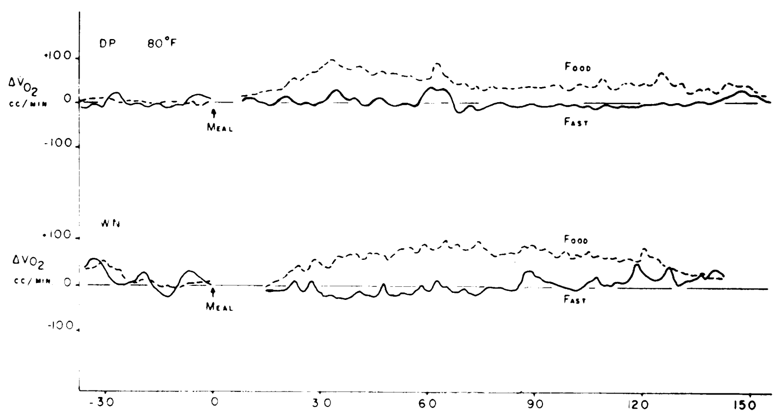

Fig. 9—Change in resting oxygen consumption (V_{O_2}) during fasting and after eating a 1000 Kcal liquid meal (40% of Kcal from protein).[17]

Peak oxygen consumption values in this subject were reached within 30 minutes after eating and declined steadily thereafter until the next meal was consumed. Note that a plot of the last measurement before each meal would reveal the same pattern as that shown in Figure 7.

With more sophisticated instrumentation a continuous record of oxygen consumption after eating has been obtained[17]. Pre- and postprandial values are shown for two subjects in Figure 9. Note that peak oxygen consumption values occur at different times in the two individuals and that muscular activity "spikes" are superimposed on rec-

TABLE IV—DAILY HEAT PRODUCTION OF PAIRS OF SUBJECTS ON EQUICALORIC DIETS

	Subjects R.B. & G.K.		*Subjects F.K. & G.S.*	
	Days on Diet	*Heat* Production (Kcal)*	*Days on Diet*	*Heat* Production (Kcal)*
Low-Protein Diet (38 gm/day)	52	4849	38	4680
High-Protein Diet (128.6 gm/day)	38	4830	52	4938
High minus Low		—19		258

* Values for heat production obtained by direct calorimetric measurements.

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ords obtained both for the fasting and fed condition. It is apparently impossible to rest for several hours while awake and voluntarily suppress all muscular activity. Nevertheless, the SDA oxygen consumption pattern appears to stand out clearly for both individuals. In summary, the normal individual following regular meal habits exhibits a characteristic diurnal oxygen consumption pattern. The energy expenditure associated with physical activity is in large measure superimposed on this characteristic diurnal change.

One of the questions that has been investigated recently is whether a high protein diet fed for several weeks will continue to elicit a higher daily energy expenditure associated with SDA than a low protein diet[18]. Table IV shows the direct calorimetric results from two pairs of subjects who were alternately fed each diet. While the results are not unequivocal, it would appear that, at least in some subjects, adaptation to high protein diets may occur as shown by a reduction in 24-hour SDA. Presumably, the diurnal pattern would remain similar but the magnitude of the increase in energy expenditure after eating would be reduced in the "adapted" individual.

While the variations in total daily energy expenditure associated with sleep, a change in resting position and SDA are not large (5 - 15 per cent), it is interesting to consider the possible alterations in these modes of energy expenditure with gain or loss of obesity tissue. If excess caloric intake becomes habitual and excess obesity tissue is gained, there is the possibility that not only do rest periods become more frequent but that rest is more complete both when awake and asleep. As excess weight is lost, energy expenditure may well increase both because of more frequent change in body position and increase in spontaneous body movement. This possibility is under study in our laboratory (the "Metabolic Chamber") at the present time.

The SDA process tends to ameliorate the consequences of excess caloric intake. The greater the number of calories consumed, the larger SDA; however, the efficiency of the SDA mechanism in combating excess caloric intake is so low (seldom more than 20 per cent of the ingested calories associated with excess oxygen consumption and perhaps no more than 5 per cent of the excess calories consumed) that a gain in weight inevitably results from excess caloric intake. On the other hand, SDA is diminished on a sub-maintenance diet. Thus, SDA contributes little, if at all, to acceleration of weight loss when the obese person restricts his caloric intake.

(c) *Personal activities:* Almost everyone spends a portion of the day attending to personal necessities. Energy expenditure levels may be fairly high for these activities, depending on: the body position used, the speed at which the activities are performed and the length of time taken to accomplish each. Passmore and Durnin[2] prepared a summary table from information in the literature and list caloric expenditure values of from 2.3 - 4.0 Kcal/min. for washing, dressing, shaving, etc. On the average, perhaps one to one and one-half hours per day are spent on personal necessities, although a large inter-individual variation and a sex difference no doubt exist.

(d) *Walking and the transport of body weight:* Almost everyone walks for a portion of each day unless bedridden or otherwise incapacitated. There are many important factors which must be considered in an evaluation of energy expenditure for walking, such as: speed, weight transported, clothing worn, surface and incline, etc. It would require a long and detailed treatise to discuss adequately all of these factors; however, body weight, at least, deserves attention in this discussion.

Figure 10, taken from the study of Montoye *et al.*[11] on Michigan State graduates, indicates that on the average males gain weight after leaving college and that this trend continues into the sixth decade before it reverses. Because men become less active after leaving college, this increase in weight is largely obesity tissue, and transport of this excess weight during walking requires energy.

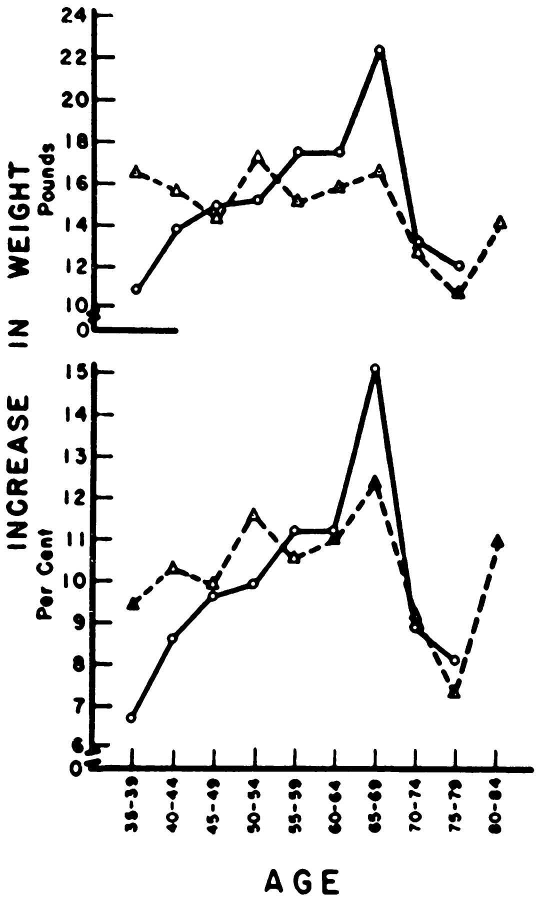

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Fig. 10—Comparison of weight increase since leaving college of athletes and non-athletes. These values are derived by subtracting weight in college from present weight. Analysis of covariance indicated no significant difference in either weight gain in pounds or per cent gain ("between" variance smaller than "within" variance).

Mahadeva *et al.*[19] have investigated the relationship between walking energy expenditure and body weight. Their findings are presented in Figure 11. Both men and women were included in the series. An energy expenditure difference attributable to sex was not found. The coefficient for the slope of the regression line for Kcal/10 minutes on body weight was 0.47.

Rough calculations from the data of Mahadeva *et al.* and the load-carrying information assembled by Passmore and Durnin[2] from the work

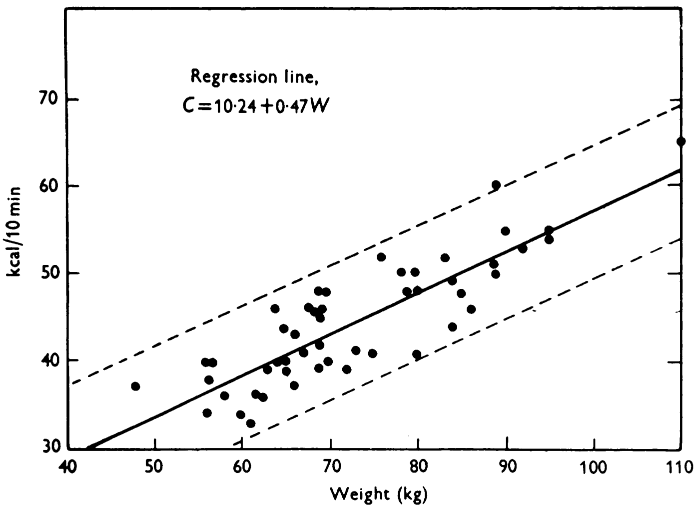

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Fig. 11—Energy expenditure during walking three miles/hr. The dotted lines show twice the standard error of estimate.

TABLE V—TABLE OF MEAN MINUTE-VOLUMES* FOR EACH WEIGHT

		Back				*Foot*			
Weight	0	4 kg	8 kg	12 kg	16 kg	0.6 kg	1.2 kg	1.8 kg	2.4 kg
Mean volume	25.06	26.02	26.38	28.91	31.21	24.78	25.73	25.45	26.59
S.E. of mean	0.49	←—— 0.46 ——→				←—— 0.46 ——→			

* Minute volume of ventilation.

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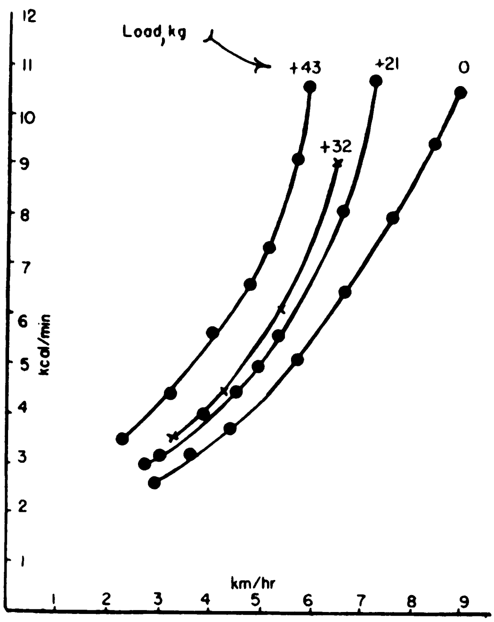
of Brezina and Kolmer and Cathcart *et al.*, presented as Figure 12, indicate that the efficiency of transporting a load in a knapsack high on the back is about the same as transporting body weight of presumably "normal" composition. This same statement cannot be made, however, if the load is shifted to the hip or to an extremity. Table V shows that the increase in minute volume of ventilation (directly proportional to energy expenditure) is roughly two to three times as great if the load is tied to the foot as compared to the back[20]. Note in Figure 12 the rapid increase in energy expenditure with all loads if walking speed is increased. With addition of more and more weight, the slope of the energy expenditure curves increases. The obese person, then, is sub-



Reproduced through the courtesy of Passmore, R. and Durnin, J. V. G. A. *Physiol. Rev. 35*:801, 1955.[2]

Fig. 12—Energy expenditure carrying loads of different speeds. Data from Brezina and Kolmer and Cathcart et al.

jected to a severe energy expenditure penalty whenever he transports his excess weight, particularly if he hurries to catch a bus or otherwise proceeds at speeds above a "comfortable stroll" pace. In obesity, the load may or may not be distributed rather evenly throughout the body. If the obesity tissue is evenly distributed, transport of obesity tissue may be a very efficient method of load-carrying. On the other hand, if the extremities are unduly loaded, transport of obesity tissue may be a very inefficient process. If the addition of obesity tissue to the limbs becomes extensive, joint action may be inhibited and chafing may occur between the inner thighs. As a result, the process of moving the body becomes a major undertaking and is avoided whenever possible, because it is so inconvenient and uncomfortable to move.

Measuring "on the job" energy expenditure: "On the job" energy expenditure information has been facilitated by the improvement of old and the development of new instrumentation. Although the Douglas bag technique for measuring oxygen consumption has served admirably for a number of years (Douglas, 1911), new materials have made this method better than ever. Light-weight latex bags[21], light-weight corrugated rubber tubing and light-weight rubber, plastic and aluminum respiratory masks and valves[1, 22] have reduced the load imposed on the subject during the measurement period. If the subject can carry light-weight equipment during the performance of his job, this eliminates the extra person sometimes used to carry the equipment for the subject. The extra person frequently interfered with the maneuverability of the subject, which led to grossly atypical results.

Another device, the Müller-Franz[23] modification of the Kofranyi-Michaelis combined gas meter and aliquoting system, which weighs about six pounds and can be easily transported by the working subject, has been widely used in Germany, Great Britain and to some extent in the United States.

More recently the IMP, or integrating motor pneumotochograph, was developed in Britain by H. S. Wolff[24]. This device measures expiratory flow rate and periodically withdraws a sample of expired air for analysis. The device weighs about four pounds, including the batteries to operate the required small motor and pump. A transmitter (an extra eight ounces) has been attached to the IMP, and ventilation volume information can be telemetered to the laboratory even though the subject is some distance away.

Energy balance studies: The results of representative energy balance studies, in which the above devices have been utilized, together with time-motion techniques for the measurement of energy expenditure, are presented in Table VI. A wide variety of working and living situations have been investigated in various places around the world. Note that most of the studies of energy balance are British, other than results obtained for military situations (Consolazio *et al.*[25], Welch *et al.* and Buskirk *et al.*[26]). On the average, the agreement between careful measurements of caloric intake and expenditure is good (± 10 per cent). It is interesting that, in most of the studies, caloric intake exceeds energy expenditure except in the one study involving dog sledging (Masterton *et al.*[29]). Whether this observation has any significance will depend on the results of similar studies in the future. The agreement obtained on a day to day basis[26] suggests that the daily difference between measured caloric intake and expenditure is random. With the addition of more energy balance studies to the series arbitrarily selected as "representative", it is suspected that an equal number of plus and minus differences will be found.

TABLE VI—REPRESENTATIVE DATA FROM THE LITERATURE FOR SIMULTANEOUS MEASUREMENTS OF DAILY ENERGY EXPENDITURE AND INTAKE

Reference	*No. of Subjects*	*Days Obs.*	*Activity*	*Intake*	*Expend.*	*Intake minus Expend.*
Consolazio *et al.*[25]	10	7	Military activities and recreation	3610	3471	139
Balke[27]	1	10	Mountaineering	5700	5150	550
Passmore *et al.*[28]	5	13	Male students, 5 days hard work 8 days sedentary	3610	3500	110
Widdowson *et al.*[6]	77	7	Military Cadets, normal training	3710	3420	290
Edholm *et al.*[5]	12	14	Military Cadets, normal training	3432	3416	16
Masterton *et al.*[29]	4	14	North Greenland Expedition, Base	3911	3581	330
also[30]	2 2	19 10	Dog Sledging	4770	5198	—428
Garry *et al.*[31]	10	7	Male clerks in colliery office	3040	2800	240
	19	7	Coal face workers	4030	3660	370
Welch *et al.*[26] Buskirk *et al.*[26]	8	17	Barrack & Bivouac Living in the Sub-arctic	3503	3280	223

Classification of physical effort: The diversity of tasks performed by man is enormous, yet we are faced with the problem of classifying physical effort in order to provide useful guidance to those responsible for health and welfare throughout the world. Many tasks are not easily classified because intricate, difficult to analyze movements are involved. In many cases, a human engineering study must be made of the man-machine-task interrelationships before further progress can be made. On the other hand, many tasks can be grouped according to the way the task affects common physiological variables, such as oxygen consumption and pulse rate.

Numerous arbitrary schemes have been devised for the classification of physical effort. For the most part, each scheme has only served the immediate needs of those responsible for it. A "classification" vocabulary acceptable to most potential users has not been adopted. To various investigators *hard* work may mean a level of work varying between 2 and 15 Kcal/min. Nor is it likely that an acceptable set of words and definitions will be adopted unless the lead of the respiratory physiologists is followed; they defined lung volumes and pulmonary function tests and standardized terminology. The classifications and definitions should be simple, convenient to use and acceptable to physiologists, nutritionists, clinicians and industrialists alike.

At least two recent attempts to grade physical work have appeared in the literature.

Christensen's classification[32] is based on the effort expended in various industrial jobs in the Swedish steel industry, which could easily be applied to professional, recreational and athletic activities as well. The physiological variables in Christensen's classification are metabolic rate and heart rate. Wells *et al.*[33], in an extension of the classification presented by Christensen, added criteria for the assessment of work level: ventilation rate and volume, R.Q., and blood lactic acid content. Wells *et al.* changed the terminology used by Christensen, dropped the 2.5 Kcal/min. level and added a 15 Kcal/min. level.

Because of the low levels of energy expenditure in many occupations, it is the author's feeling that an intermediate classification between 1.0 and 5.0 Kcal/min. is necessary. Ventilation volume should prove to be a useful addition to an adopted scheme, because of the possibility of telemetering ventilation volume as well as heart rate. There is a direct relationship between heart rate, ventilation volume and metabolic rate under a wide variety of conditions; therefore, these simple measurements should prove valuable in assessing "on the job" energy expenditure. It is felt that the measurement of blood lactic acid content would not add appreciably to a classification scheme because of the difficulties of drawing blood at the proper times for evaluation of the anerobic component for a given job.

On the basis of the ideas presented by Christensen and Wells *et al.*, review of the literature and first-hand experience, the combined scheme presented as Table VII may satisfy many requirements.

The physiological parameters related to metabolic rate that are easily measured, ventilation volume and heart rate, are included in Table VII. Since one purpose of such a table would be the estimation of the energy expenditure for a given task, it follows that the measurement of choice in this instance would be oxygen consumption. Measurement of oxygen

TABLE VII—CLASSIFICATION OF PHYSICAL EFFORT

Classification	$\dot{V}$	$\dot{V}_{O_2}$	*M.R.*	*P.R.*
Very light	10	0.5	2.5	80
Light	10-20	0.5-1.0	2.5- 5.0	80-100
Moderate	20-35	1.0-1.5	5.0- 7.5	100-120
Heavy	35-50	1.5-2.0	7.5-10.0	120-140
Very heavy	50-65	2.0-2.5	10.0-12.5	140-160
Unduly heavy	60-85	2.5-3.0	12.5-15.0	160-180
Exhausting	85	3.0	15.0	180

$\dot{V}$ = ventilation volume in liters per minute

$\dot{V}_{O_2}$ = oxygen consumption in liters per minute

M.R. = caloric expenditure in Kcal per minute

P.R. = pulse rate in beats per minute

The values listed apply to steady state work and also to peak effort as used in the diagram prepared by DuBois *et al.* (See Figure 13.)

consumption should take into account the oxygen debt, unless the work can be done in a "steady state" and measurements are made during the "steady state" period.

It should be emphasized that under certain conditions one or more of the variables listed in Table VII may fail to yield a valid estimate of the severity of the work but rather emphasize an emotional component such as fear, or fail to emphasize a "fitness" component, such as nutritional status during semistarvation. If pulse rate is the variable in question, fear or apprehension may yield abnormally high working pulse rates, whereas semistarvation produces abnormally low pulse rates.

The deficiency in Table VII is that body mass or size and physical fitness have not been taken into account. Perhaps the simplest method to correct for body size would be to express oxygen consumption and metabolic rate as the number of times basal metabolic rate, that is, two times, four times, etc. This type of expression has appeared in the temperature regulation literature and the term "met" for one times basal metabolic rate has been adopted. This approach assumes, however, that one either knows or is willing to estimate basal metabolic rate. For the time being it is felt that a correction for body size, while desirable, might only hinder wide adoption of a simple scheme for the classification of physical effort. Physical fitness for work is more difficult to cope with. In general, classification problems associated with age, disease, etc. could be

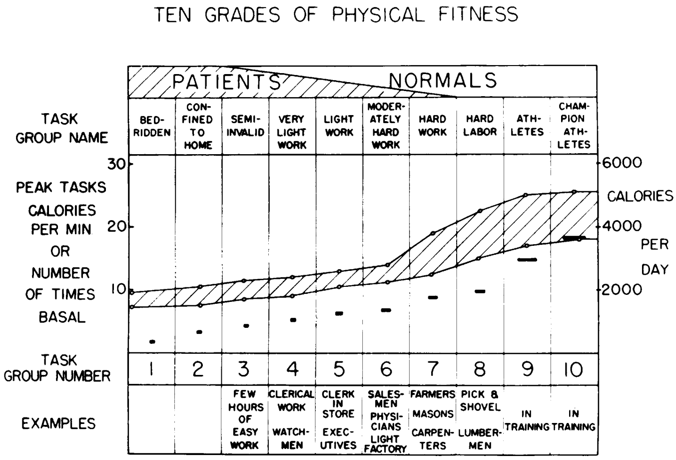


Fig. 13—*10 Grades of Physical Fitness*

At the top of the graph there is a box giving the usual division of experimental subjects into patients and normals. The line between these is made diagonal to show that there is a lapping of patients and normals when it comes to light work and even hard work, since some who are classified as patients can do hard work. The second box at the top of the chart shows 10 grades of activity ranging from bed-ridden patients to athletes, and at the bottom of the chart the various occupations are graded arbitrarily in the same manner. In the middle of the graph there are two curves representing roughly the estimated caloric expenditure for 24 hours for the people in the different groups. This estimate of caloric expenditure has been made from survey of the food consumption of people in different occupations, a method that is not very accurate but the best available at the present time. Below these two curves comes a series of bars representing roughly the peak tasks of the different occupations in terms of calories per minute or number of times basal. These could be represented in terms of oxygen consumption per minute but calories are used as they are better understood by most people. The height of the bar above the base line represents the calories of the peak tasks and the length of the bar is intended to represent roughly the duration of the task. Much more information is needed regarding the peak tasks in various American occupations as there are great differences in various institutions and individuals.

For groups 1 and 2, patients who are bedridden or confined to the home, the total caloric expenditure present per day is close to the hourly basal metabolism multiplied by 24 with perhaps an additional 6 per cent for the average specific dynamic action throughout the day. Allowance should be made for peak tasks and other forms of exercise and allowance for the higher basal metabolism found in fever and certain diseases. The peak tasks of patients in groups 1 and 2 are perhaps represented by the exertion involved in being admitted to the hospital or by the relatively hard work of using the bed pan or commode. Group 3, the semi-invalid, usually has as a peak task the work of getting into a chair or perhaps walking the length of the room. In these tasks, the oxygen consumption depends on the awkwardness of the individual and perhaps on the inefficiency of his muscles caused by disease. In recent times, a good many people classified as semi-invalids have been able to hold regular jobs and perform several hours of easy work.

(Illustration from an article submitted for publication by the late Eugene F. DuBois and co-workers, entitled "An Attempt to Classify Occupations in Ten Task Groups According to Physical Exertion, or According to the Amount of Physical Exertion Demanded.") To be published: *Proc. Amer. Phil. Soc. 104*, Feb. 1960. Reproduced by permission of the American Philosophical Society.

considered as those basically arising because of different levels of physical fitness. Perhaps the easiest way to express the values in a classification table is in relative terms, that is, relative to the maximal work capacity. Tests are available for assessing maximal working capacity[34-36]; however, one would have to either measure maximal working capacity or estimate it from submaximal values. Again, this may be an unneccessary complication and would thwart wide acceptance of a simple classification of physical effort.

Just before his untimely death, E. F. DuBois prepared a diagram (generously provided by his son, A. B. DuBois), in which he divided the adult population into task groups and presented data for both energy expenditure during peak effort and daily energy expenditure in one figure (Figure 13). The legend for the figure is largely self-explanatory. While one might quibble with the title, "10 grades of physical fitness", the choice of words for subgroups (Hard work vs. Hard labor), and his statement that physicians do *moderately hard work*, the energy expenditure summary is presented in a clear and useful fashion.

Work is usually intermittent and not continuous; therefore, time-motion information is also needed to tell us whether work should be called *hard* because of one peak effort, several peak efforts, or because of sustained effort below peak values. Thus, a rating or ratings of the work performed plus time-motion information plus summary information similar to that prepared by DuBois is essential for a more thorough physiological understanding of caloric requirements.

SUMMARY

If a thorough physiological assessment of caloric requirements is undertaken, proper consideration should be given energy expenditure as well as caloric intake. Various factors influencing the diurnal, weekly and seasonal patterns of energy expenditure were discussed. These include sleep, the "specific dynamic action" of food and physical activity. The results of combining data on caloric intake and expenditure in order to establish assessments of energy balance for several "on the job" situations were mentioned together with a brief review of the newer techniques used to measure energy expenditure.

The problem of classification of physical effort was discussed in relation to: 1) definition and standardization of terms, 2) classification of the working and recreating population into subgroups according to

level of physical activity, and 3) the necessity for time-motion information.

Throughout the discussion the fact was emphasized that we, in the United States, do *not* have adequate information concerning the rate of energy expenditure associated with various occupations and recreational activities. There may be several reasons for this deficiency: 1) lack of a laboratory devoted to the study of industrial hygiene and work physiology*, 2) lack of interest on the part of investigators to undertake routine energy expenditure measurements on large numbers of people, and 3) lack, until recently, of miniaturized equipment for measuring energy expenditure without altering the task undertaken by the subject.

* Similar to the German Max Planck-Institut für Arbeitsphysiologie or the Finnish Institute of Occupational Health.

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