Obesity: physical activity and nutrition

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With the work of Lavoisier (Lavoisier & de Laplace, 1780) it became possible to construct balance sheets regarding energy intake (measured by the caloric value of the food) and energy expediture. It is frequently claimed by nutritionists that for weight maintenance these two must balance and if they do not obesity or weight loss will occur. Those daring to doubt this proposition have often been accused of challenging the laws of thermodynamics, and it is of interest to know which of these laws is referred to. The first, which concerns the conservation of energy and may be summarized as 'you can't get something for nothing', gives no indication of what factors to use to convert the gain of body energy into gain in weight; and the second, succinctly summarized as 'you can't even break even', explicitly states that in any dynamic situation there is an inevitable loss of energy in the form of entropy. Neither of these laws supports the accusation made because in weight reduction there are usually changes in body composition, particularly in body water (Keys & Brožek, 1953), and there is much evidence to show that the efficiency of metabolic processes is a variable factor. However, it is a truism to state that

$$\triangle \text{ body calories} = \text{calories in} - \text{calories out.} \qquad (1)$$

Redfearn (1965) has claimed that 'this is one of the basic facts of nutrition, but its simplicity is often obscured by the mystique created in the endless flow of books and articles on diet, dieting and slimming'. This may be true, but we wish to suggest that this simple statement is a superficial description of a very complex situation. We would like, therefore, to examine the factors that influence the components in equation (1).

Factors influencing food intake

Although the emphasis in this paper will be on the effects of exercise, for the sake of completeness it is essential that we list the factors that influence food intake, of which activity is but one. In terms of comparative nutrition, the biggest factor is of course body-weight. In a study of a number of species ranging from mouse to elephant, Brody (1945) recommends that the calorie intake necessary for weight maintenance is 140 kcal/kg$^{0.75}$, and Miller & Payne (1963) have suggested a minimum calorie requirement of 107 kcal/kg$^{0.75}$. That these allowances also apply within a species has been shown for the rat (Heusner & Harmelin, 1963); although there may be a trend for big men to eat more than small men (Garry, Passmore, Warnock & Durnin, 1955; Grossman & Sloane, 1955), this effect is probably overridden by other factors (Thomson, Billewicz & Passmore, 1961). Climatic factors in the control of food intake—such as temperature, humidity and wind velocity—will be discussed in their relation to man later in this Symposium, but it seems well established that animals kept below thermal neutrality increase their food intake inversely with temperature (Jacob & Payne, 1964). This has been made use of by some zealous breeders of laboratory animals who found that it was cheaper to use fuel to warm their animal houses than to buy more food. Above the region of thermal neutrality, food intake falls off abruptly (Hamilton, 1963), although under extremely hot conditions calorie requirements are said to rise owing to the extra requirement for work to maintain homoeothermy (Consolazio, Matoush, Nelson, Torres & Isaac, 1963).

During the last 20 years human nutritionists have been impressed by the ability of some men to maintain their body-weight between the age of 20 and 60 despite a throughput of approximately 55 tons of food. Clearly there is some precise control over body-weight, and several possible mechanisms have been suggested for the control of voluntary food intake; we would argue that the intake of food is not the only possible point of control, and that in all probability a number of mechanisms act simultaneously in order to obtain the precision required. Stomach distension (Carlson, 1914) seems ineffective in modern man since he tends to eat frequent, small meals. Some of the proposed controls, e.g. the glucostatic theory of Mayer (1953), operate as the food is absorbed, but it seems improbable that such mechanisms can match the calorie demand of the previous hours with any degree of accuracy (Edholm, Fletcher, Widdowson & McCance, 1955; Durnin, 1961). Also, Yudkin (1963) who distinguishes between hunger (a demand for calories) and appetite (a demand for a particular food) has pointed out that such mechanisms can be overridden when a meal containing a number of courses is offered. The lipostatic theory of Kennedy (1952–3) which suggests that appetite is regulated by the amount of fat stores in the body appears to overcome this disadvantage. Intermediary between these two extremes is the thermostatic theory of Brobeck (1948) who makes the interesting proposition that appetite is controlled by the specific dynamic action of the food consumed; the influence of specific dynamic action on calorie balance is discussed in more detail below. However, in view of the fact that the obese do not necessarily eat more than average (Johnson, Burke & Mayer, 1956; Stefanik, Heald & Mayer, 1959; McCarthy, 1966), the importance of these mechanisms should not be overstated.

Palatability is a very difficult factor to assess in man because of marked cultural preferences. However, sweetness seems to be universally prized. For many years slimming diets have been constructed by lowering the amount of carbohydrate consumed and owe their success to an overall reduction in calorie intake. On the other hand, in both animals (Miller & Payne, 1961) and man (Dole, Dahl, Schwartz, Cotzias, Thaysen & Harris, 1953), food consumption is raised by increasing the protein content of bland diets. Certainly it is possible to increase the amount of food taken by damaging the hypothalamus of rats (Brobeck, Tepperman & Long, 1943). The influence of psychological factors on food intake is beyond the scope of this paper, except perhaps to mention that men involved in extreme feats of physical performance often have bizarre food preferences.

More pertinent to this Symposium is the influence of exercise on food intake. This has been studied experimentally by Mayer, Marshall, Vitale, Christensen, Mashayekhi & Stare (1954), who showed that the food intake of both rats and mice could be influenced by the duration of exercise. When mature rats accustomed to a sedentary existence were exercised in a treadmill for increasing daily periods, it was observed that for short periods of exercise there was no corresponding increase in food intake. In fact food intake decreased slightly but significantly; body-weight also decreased. For longer durations of exercise food intake increased linearly and weight was maintained. For very long durations of exercise, the animals lost weight, their food intake decreased and their appearance deteriorated. If applicable to man, the results of these experiments would indicate that a small amount of exercise has an effect on body-weight, but that in the range of normal activity there seems to be little advantage. However, there are pitfalls in applying to man the results of experimental studies with small animals because of differences in the proportion of total metabolism that is expended doing work. It is well established that basal metabolism is related to body-weight to the power of three-quarters (Kleiber, 1961), whereas from a consideration of simple mechanics the energy cost of exercise is related directly to body-weight (Garry *et al.* 1955; Miller & Blyth, 1955; Wyndham, Walker & Morrison, 1964). If we take the figure given by Brody (1945) of 0·5 kcal per kg per km as the net energy of walking, and apply this figure to Mayer's data we find that only about 3% of the total energy turnover of his most severely exercised rats (*c.* 10 km/day) is used for work. A walk for a similar distance by a man would amount to 10% of his total energy expenditure, and for an elephant 22% (see Table 1). In addition, these figures must be considered in relation to the magnitude of the task for each; Mayer's rats were exhausted, whereas 10 km for a man might be regarded as an afternoon walk. Certainly the energy cost of activity for small laboratory animals must be regarded as a negligible proportion of their calorie requirements. It remains to be explained therefore what Mayer's rats did when they doubled their calorie intake and only increased their calorie demand by 3%. In view, however, of the fact that in man moderate activity can contribute significantly to energy needs, it is not surprising that appetite and food intake are increased by activity, although the response may be delayed (Edholm *et al.* 1955; Durnin, 1961).

Table 1. *Relationship between energy requirements for maintenance and exercise*

			10 km walk	
Species	Weight (kg)	Maintenance* (kcal)	kcal†	As % of total energy
Elephant	3700	67000	18500	22
Man	65	3000	330	10
Rat	0·3	60	2	3

*140 kcal per kg body-weight$^{0.75}$. †0·5 kcal per kg body-weight per km.

Factors influencing calorie output

In sedentary man the basal metabolic rate (BMR) accounts for more than half of the total calorie output. Various formulas are available for calculating values for BMR, but they all have weight as an important component. From these formulas people would be expected to have a larger metabolic rate the more weight they put on, and there are sufficient measurements in the literature to show that this is substantially true (Davidson & Passmore, 1963). It is customary for nutritionists to take BMR as a baseline for calorie requirements. In so doing they frequently ignore the highly specific conditions under which BMR is measured (i.e. lying at rest within thermal neutrality after an overnight fast) and apply the measurement as though it represented a minimal calorie need. The value does not include the energy requirements for protein synthesis, nor any residual effects from previous exercise or diet. Miller & Payne (1961) have estimated the former to be 50% of basal metabolism, but this effect is often classified as specific dynamic action which is discussed below. Energy expenditure during recovery from exercise is pertinent to this Symposium. Kleiber (1961) has pointed out that neither Brody nor Zuntz seems to have allowed for the increase in metabolic rate over BMR following the performance of work, and went on to show that the net efficiency of a horse would fall from 25% to 21% if this factor was taken into account. Herxheimer, Wissing & Wolff (1926) reported a 10% increase in man's BMR for as long as 48 h after strenuous exercise, Edwards, Thorndike & Dill (1935) described a 25% increase 15 h after playing football, and Gelineo & Barić (1951) a 21% increase after 6 days. Similar increases have been reported following exposure to the cold (Kang, Song, Suh & Hong, 1963). We have recently made some measurements that support these findings. Two young men who doubled their normal activity showed a mean increase in BMR of 14% the following morning. These observations are of importance in the treatment of obesity by exercise because they suggest that the metabolic rate is raised not only during the period of the task. We may calculate that the extra energy cost to a business man who plays a game of golf is relatively small, but if the exercise stimulates his metabolism long enough it could make a significant difference to energy balance. Clearly there is a need for more work in this field.

Activity is associated with both work done on the environment and, in keeping with the second law of thermodynamics, heat lost owing to muscular inefficiency: both dissipate body energy and increase calorie requirements. With the introduction of socially acceptable devices for measuring oxygen consumption it has been possible to estimate the energy cost of a wide range of normal activities, and these have been collected together in an excellent review by Passmore & Durnin (1955). From their data it is possible to calculate activity equivalents of 1 lb of body fat, e.g. 100 holes of golf, or twenty sets of tennis, or a walk from London to Brighton. The enormity of these tasks is discouraging to obese subjects. In answer to this criticism Mayer (1953) has pointed out that a moderate activity such as splitting wood for half an hour a day for a year would represent the calorie equivalent of 26 lb of body fat, and he argues that decreased activity may be an aetiological factor in the development of obesity. We are not convinced that increasing the calorie output by a regular but small amount is cumulative because the proposition does not take into account the dynamic state of metabolism, and the implication is that the subject has no weight control mechanism that could cope with these trivial changes in energy output. The argument is however tenable if one can suppose that the cost of the exercise is greater than conventionally accepted. This could occur in two ways: by increasing metabolic rate for a long period after the task has been completed, or if the efficiency of food utilization depends upon the amount of exercise. Recently we have been investigating the latter by determining the thermic effect of a meal under conditions of rest and whilst exercising, and we have found that it is greater when subjects are exercised (see Table 2). The figures indicate an advantage to the obese subject of exercising following a meal or at least indicate that some advice should be given concerning the pattern of eating. There is a danger of obesity developing in those people who eat the bulk of their calories before going to bed ('night-eating syndrome'; Stunkard, Grace & Wolff, 1955; Fryer, 1958). Consistent with these findings is the work of Fabry, Fodor, Hejl, Braun & Zvolánková (1964) on man that shows that gorgers tend to put on more weight than nibblers.

Table 2. *Thermic effect of a meal measured in man at rest and whilst exercising*

(Mean values for twenty-four determinations on six subjects)

	Fasting metabolic rate (kcal/h)	Postprandial rise (kcal/h)	% increase over BMR
Resting	67	17	25
Exercising*	278	36	54

*Twelve steps of 11 in per min.

Unfortunately the term specific dynamic action (Rubner, 1902) has been widely used as though it applied specifically to protein in the diet. However, it is now clear that the effect depends upon the nutrient balance of the diet (Kleiber, 1945–6; Miller & Payne, 1962; Kekwick & Pawan, 1957), and in view of this we prefer the more general term thermic effect. Values are increased not only during exercise but also by the quantity of food consumed. We have now overfed sixteen young adult human subjects for periods up to 2 months by increasing the calorie intake by at least 1300 kcal/day. When they ate a diet of ordinary composition, the volunteers gained weight initially, but their rates of gain fell throughout the trial; on the other hand, when they ate a low-protein, high-calorie diet their weights were substantially constant (Miller & Mumford, 1964; Brown, Miller & Mumford, 1965; see also Doyle, Morse, Gowan & Parsons, 1965; Ashworth, Creedy, Hunt, Mahon & Newland, 1962). Measurements of activity by pedometer showed no change during the experiment, nor was there any change in BMR as usually defined. However, the oxygen consumption measured over 24 h does correspond to that required to oxidize all the food eaten, thus indicating an overall increase of metabolic rate in response to the increased food consumption. The thermic response to meals was higher and for a longer period of time, which is consistent with the data of Passmore & Ritchie (1957) which show a similar effect during overfeeding. These results help in the interpretation of the experiment of Mayer *et al.* (1954) with exercised rats, and would indicate that the extra food consumed which was not being used for the exercise was being burnt off and converted into heat. This process of losing surplus energy has been termed *Luxuskonsumption* (Neumann, 1902) and provides a possible control mechanism for body-weight. If this control is set too high in the obese subject (Nadal, Nel & Ravina, 1954), exercise may provide an alternative means of inducing an increased metabolic rate.

Thermogenesis is possible under other conditions, and there is a considerable literature on non-shivering heat production when exposed to the cold (Smith & Hoijer, 1962). Increased metabolic rates have also been observed during periods of nervous tension such as landing an aeroplane (Corey, 1948; Udalov & Šibuneev, 1963), a factor which might apply to athletes in competition. The rate of heat loss will depend to some extent on thermal insulation which is higher in the obese (Quaade, 1964). Finally, losses of carbon- and energy-containing compounds can reach significant proportions in the urine and faeces of obese subjects eating a calorically restricted diet (Pawan, 1966). One possible explanation of these experiments is that endogenous losses have become a large fraction of the total losses, and must be taken into account in metabolic studies of slimming.

Interrelationships between the calorie input and output

We would like now to return to our original theme that body-weight is controlled by a very complex set of factors. We have described those factors that influence the components in equation (1) but many are interrelated, e.g. calorie output is influenced by body-weight because of its effect on basal metabolism and exercise. Similarly, food intake is influenced by the amount of exercise, but at the same time itself influences the amount of heat production by the body; in particular exercise will increase the energy losses from the body but may at the same time increase food intake. However, the quantitative aspects of these factors on calorie balance are not known with any degree of precision and there is a need for further research. It is not surprising that for any given weight, age, or sex it is possible to find individuals who customarily eat twice as much as others (Widdowson, 1947; Rose & Williams, 1961).

Most of the experimental evidence that we have cited concerns normal individuals because there is a paucity of good experimental papers dealing with the obese, many of which are contradictory probably because it is not stated whether the subjects were in the dynamic or static phase of obesity (Rony, 1940). It is more fundamental to ask why people become obese than how to slim them. In this respect the work of Rolly (1921) is of interest because he was able to determine the specific dynamic action in the same person before and after the development of obesity and showed that this was reduced to practically zero. Rony (1940) cites six papers that say the thermic effect of food is low in the obese, and three papers that say it is normal, but none of the measurements were made whilst the subjects were exercising. Unfortunately there is conflicting evidence concerning the extent to which the obese exercise. Bullen, Reed & Mayer (1964) claim that the obese take exercise less frequently than normal people and that when they do they are less active. On the other hand, Dorris & Stunkard (1957) and McCarthy (1966) show no difference between the physical activity of obese and normal subjects. Similarly, evidence about the muscular efficiency of the obese is also contradictory. Gessler (1927) and Bernhardt (1929) claim that the obese produce less heat than average, and even claim a negative

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phase following work. On the other hand, Du Bois (1936) concluded that the average obese subject is slightly less efficient than normal. Much of this controversy might be resolved if one knew whether the subjects were gaining weight or had stabilized their weight at a high level. For example, Nadal *et al.* (1954) report on the difficulty of fattening 98 kg people to qualify for the '100 kilo Club'. Since some sedentary normal subjects can also overeat without putting on weight, in contrast to the obese in their dynamic phase, there is a prima facie case to look for factors causing obesity other than gluttony or sloth.

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Age, physical activity and energy expenditure

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Let me begin by confessing that I am quite unable to correlate satisfactorily the three topics contained in the title of my talk. I hope I can give some factual description of levels of physical activity and energy expenditure in population groups covering a wide age-span. But neither I nor, I believe, anyone else can relate, in man, alterations in physical exercise to ageing, in a quantitative sense. We all have subjective impressions, based on a certain amount of evidence, that physical activity is less enjoyed and that it takes up less time with advancing age. However, the general truth of the statement does not tell us much about the several facets of this interesting question: How rapid is the decline? Does it apply only to leisure or to occupational exercise too? Is there ever very much physical activity in a population after the years of childhood? Is the decline in exercise with age physiological, or does it only reflect social conditions? These and many other questions are open only to speculation at present, because of the lack of good experimental information.

In this paper I propose to deal almost entirely with results from my own laboratory. This is partly because there is very little published material which gives a sufficiently detailed description of the physical activity of individuals throughout a period of some days. It also depends on the fact that I am interested in relationships between the time spent in physical exercise and various properties of body build or body composition, and with total quantities of daily energy expenditure. The source of information has thus been restricted but there are still data on some hundreds of individual people of a variety of age, sex, body build, social group and occupation.