Dependence of 24 h energy expenditure in man on the composition of the nutrient intake

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1. The influence of the nutrient composition of food on energy expenditure during a 24 h period was investigated in adult volunteers. The maximum probable effect was determined using iso-energetic diets high in either protein or in glucose.

2. Two men and four women took part in the study. Their body-weights and body composition were within the normal range. Each subject lived for 28 h in a whole-body calorimeter set at 26°, on two separate occasions. During each session they ate one of the following iso-energetic diets: high-protein–low-carbohydrate or high-glucose–low-protein. Energy expenditure was determined while the subject followed a pre-set pattern of activity. A 24 h collection of urine was made and total nitrogen, creatinine and urea excretions were determined, so that heat production could be corrected for protein metabolism.

3. Two independent measures of energy expenditure were made: direct calorimetry was used to obtain heat loss partitioned into its sensible and evaporative components, while indirect calorimetry was used to estimate heat production from oxygen consumption, carbon dioxide production and N excretion. There was good agreement between the two estimates of 24 h energy expenditure: for the twelve sessions in the calorimeter the mean difference between heat production and heat loss was only 0·4 (SEM 0·39)%.

4. The results showed that nutrient composition can have a marked influence on 24 h energy expenditure in adult humans. Mean values of 8659 (SEM 230) kJ and 7735 (SEM 250) kJ were obtained for the high-protein and high-glucose diets respectively. This 12% increase in energy expenditure on the high-protein intake was significant ($P < 0·001$). On the high-glucose intake, total heat loss comprised 22 and 78% evaporative and sensible heat losses respectively. The increase in heat loss on the high-protein intake was accounted for by a 39% increase in evaporative heat loss and a 7% increase in sensible heat loss.

5. It is concluded that the composition of the nutrient intake has a greater influence on the metabolic rate of adult humans than has been suggested by some groups of workers in recent years.

Investigations made earlier this century showed that the nutrient composition of the diet could influence energy metabolism. In particular, a high protein intake elevated the metabolic rate after feeding in the dog (Rubner, 1902; Lusk, 1928).

More recently, it has been shown that the energy expended over 24 h by farm animals can also be affected by the nutrient intake (Blaxter, 1967). Not only is the resting metabolic rate (RMR) immediately after a meal influenced by nutrient composition, but also the RMR measured between 12 and 20 h after the last meal can be influenced by the composition of the meal (Dauncey & Ingram, 1979). A high-protein intake significantly increased the RMR of piglets after 20 h, whereas a high glucose intake did not affect the value obtained 12 h after feeding.

However, in man it has been concluded that the increase in RMR after a test meal was independent of the nutrient composition (Garrow & Hawes, 1972). The authors suggested that it was doubtful whether anyone had shown a greater effect on RMR, in man, of eating protein rather than carbohydrate or fat. Nevertheless, other workers found that amino acids had a greater effect than glucose on the RMR during the 150 min following a meal, although

Table 1. *Description of subjects*

Subject no.	Male (M) or female (F)	Age (years)	Weight (kg)	Height (m)	Wt for height actual minus ideal* (%)	Surface area† (m^2)	Body fat‡ (%)
1	M	29	67·5	1·78	−1·6	1·84	8·1
2	M	29	65.0	1·81	−9·3	1·84	9·7
3	F	31	54·1	1·67	−4·8	1·60	21·5
4	F	27	55·2	1·70	−10·1	1·64	21·3
5	F	24	65·3	1·67	+9·6	1·74	24·7
6	F	22	79·3	1·74	+23·6	1·94	33·8
Mean	—	27	64·4	1·73	+1·2	1·76	19·8
SEM	—	1·4	3·8	0·02	5·3	0·05	3·9

* Ideal weight taken as mid-point of medium-frame size, from Metropolitan Life Insurance Company, New York (1960).

† From DuBois & DuBois (1916).

‡ From sum of four skinfold thicknesses (Durnin & Womersley, 1974) and expressed as a percentage of body-weight.

they concluded that the difference was less than classically admitted (Pittet *et al.* 1974). More recent work with man has again suggested that the composition of the diet is unimportant with respect to energy metabolism (Rosenberg & Durnin, 1978).

The investigations reported here were therefore carried out to determine the maximum probable effect of nutrient composition on the 24 h energy expenditure of 'normal'-weight human adults. A preliminary account of part of this work has been published (Dauncey, 1979*a*).

METHODS

Subjects

Six volunteers took part in the study: two men and four women.

Physical characteristics of the subjects are given in Table 1. The range of body-weight and body composition was relatively wide but none of the subjects was either markedly overweight or underweight and all were apparently in good health. The mean value for actual weight-for-height was only 1% greater than the 'ideal' weight-for-height as specified by the Metropolitan Life Insurance Company, New York (1960), and subject no. 6 showed the greatest departure from the 'ideal' value.

The investigations were approved by the Ethical Committee of the MRC Dunn Nutrition Unit.

Experimental procedure

Each subject lived in a calorimeter designed for human occupation (Dauncey *et al.* 1978) at an ambient temperature of 26° on two separate occasions, each of 28 h and separated by an interval of 1 month. Two of the subjects had lived in the calorimeter on previous occasions; the other four were all familiar with laboratory work and were given full instructions on the normal procedure inside the calorimeter before the investigation was begun.

Each subject lived in the calorimeter from 09.30 hours on day 1 until 14.00 hours on day 2. Standard clothing of thin cotton shirt and trousers was worn. The posture of the subject was standardized with most of the day-time spent sitting. During this time the subject could read, write, use the telephone, listen to the radio or watch television. In order to minimize any differences in the energy expenditure for the two sessions which might have been due

Table 2. *Intake of nutrients and energy during 24 h in the calorimeter*
(24 h intake was divided equally into three meals)

Treatment...	Protein	Glucose
Nutrient (g)		
Protein	225	21
Fat	134	134
Sugars	39	255
Starch	58	57
Dietary fibre	13	13
Metabolizable energy		
Total (kJ)	10330	10324
Percentage from:		
Protein	37	3
Fat	48	48
Sugars	6	40
Starch	9	9

to differences in minor activity and small movements, the subject was asked to carry out similar activities during both sessions. Two 30 min periods of cycling on a bicycle ergometer (Monark; Monark-Crescent AB, Varberg, Sweden) were carried out between 14.00 and 14.30 hours and between 18.30 and 19.00 hours. The subject exerted a force of 5 N at 50 rev./min which represented a work load of 1·5 kJ/min. The subject went to bed at 22.30 hours, after a 30 min period of standing to prepare for bed. The subject usually slept well, and got out of bed at 09.30 hours on the second day, put away the canvas folding-bed, pillow and two cotton sheets and was then given a meal. The rest of the morning was spent sitting down, from 10.00 until 14.00 hours. Meal times were also standardized (see p. 4).

All urine excreted was collected by the subject for future chemical analysis. It was divided into four collections: 'pre-24 h' from 09.30 to 14.00 hours on day 1, and the '24-h' collection comprised 14.00–22.30 hours on day 1, 22.30–09.30 hours overnight and 09.30–14.00 hours on day 2.

Body-weight, height and skinfold thickness were measured before and after the calorimeter period. Mean values of the two sets of measurements were calculated. The subject was asked to comment on the environmental temperature, in relation to comfort, and on the food intake.

Food intake

Before entering the calorimeter. Each subject recorded everything eaten and drunk during the week before the first session in the calorimeter. Dietary intakes were then calculated using McCance and Widdowson's Food Tables (Paul & Southgate, 1978). In the week before the second session the subjects were asked to eat the same foods as in the week before the first session, to minimize the influence of the previous day's intake on energy expenditure (Dauncey, 1980). At 09.00 hours, before entering the calorimeter, the first standard meal was eaten (see next section).

In the calorimeter. One of two diets was provided in the calorimeter: high protein–low carbohydrate (Protein diet) and high glucose–low protein (Glucose diet). These diets were chosen on the basis of earlier work with other animals (Dauncey & Ingram, 1979) as being the two most likely to produce the greatest difference in their influence on the metabolic rate of humans. Each subject received both diets at an interval of 1 month; the order was randomized.

The diets were planned to be as normal as possible and were based on sandwiches and

desserts. The Protein diet was based on roast beef and cheese, while the Glucose diet was based on a strawberry-flavoured dessert. Both diets were calculated to provide 10·3 MJ/24 h. A greater intake was not practical because of the difficulty of eating more beef. The intakes of the major nutrients, dietary fibre and energy are given in Table 2. The daily intake was divided into three identical meals which were given at 09.00 (before entering the calorimeter), 13.30 and 18.00 hours on day 1. A fourth identical meal was provided at 09.30 hours on day 2.

Energy expenditure

Energy expenditure was measured by two independent techniques: direct calorimetry, as total heat loss estimated from its evaporative and sensible (i.e. non-evaporative) components, and indirect calorimetry, as total heat production estimated from oxygen consumption and carbon dioxide production.

Measurements were made in the whole-body calorimeter as described by Dauncey *et al.* (1978). Sensible heat loss (SHL) was estimated from the temperature difference across a water-cooled heat-exchanger, and evaporative heat loss (EHL) was estimated from a knowledge of the difference in the moisture content of air entering and leaving the calorimeter chamber. Full calibrations for SHL and EHL were made before the investigation and sensible heat calibrations were also made during the 24 h before, and after, the subject occupied the calorimeter. This was done to ensure that any small changes in water flow-rate through the heat exchanger had a minimal effect on the estimate of heat loss.

Heat production was calculated from a knowledge of the O_2 and CO_2 concentrations of air entering and leaving the chamber. The paramagnetic and infra-red gas analysers that were used were calibrated immediately before the subject went into the calorimeter.

Correction of heat production for protein metabolism. The urine samples collected by each subject were analysed for total nitrogen by the Kjeldahl method (Tecator Kjeltec System I; Tecator Ltd, Bristol, England) and for urea and creatinine by standard methods of autoanalysis. From a knowledge of the total urinary N, and the energy and respiratory quotient (RQ) values for carbohydrate, protein and fat, the proportions of the total O_2 and CO_2 associated with protein metabolism and the protein and non-protein RQ values were calculated. Total heat production was then calculated from that associated with the oxidation of fat and carbohydrate and that due to protein (Zuntz, 1987; Lusk, 1928; Cathcart & Cuthbertson, 1931; Weir, 1949). The corrected and uncorrected values for heat production were compared and the correction was expressed as a percentage:

$$\frac{\text{Uncorrected} - \text{Corrected}}{\text{Corrected}} \times 100.$$

Statistical analysis

To determine the effects of the nutrient composition of the food intake on energy expenditure, Student's paired t test was considered to be the most appropriate form of statistical analysis. This test was used, therefore, to compare the effects of the Protein and Glucose diets.

RESULTS

All the subjects found the living conditions in the calorimeter acceptable. The amount of exercise was judged to be within the range found in everyday life. The meals were all eaten within the 30 min period available, with the Protein meals taking the longest to eat, even when the meat was minced.

Table 3. (*a*) *24 h urinary excretions (mmol) of total nitrogen, urea and creatinine, from 14.00 hours on day 1 until 14.00 hours on day 2 and* (*b*) *values (mmol/time-period) for excretions of total N, urea and creatinine during the first day, night and second day in the calorimeter*

(Mean values with their standard errors)

(*a*)	Total N		Urea N		Creatinine	
Treatment*... Subject no.	Protein	Glucose	Protein	Glucose	Protein	Glucose
1	1793	494	1612	421	19	14
2	2126	621	1601	548	18	14
3	2085	510	2050	453	16	12
4	1987	497	1714	435	14	10
5	2061	473	1900	402	16	11
6	1852	486	1796	434	19	12
Mean	1984	514	1779	449	17	12
SEM	55	22	71	21	0·9	0·7
Statistical significance of difference between treatments: *P*	<0·001		<0·001		<0·001	

(*b*) Time-period...	Day 1 (14.00–22.30 hours)		Night (22.30–09.30 hours)		Day 2 (09.30–14.00 hours)	
Treatment...	Protein	Glucose	Protein	Glucose	Protein	Glucose
Total N						
Mean	773	224	849	175	361	115
SEM	43	14	36	7	16	8
Urea						
Mean	702	199	759	150	331	100
SEM	46	12	45	10	15	6
Creatinine						
Mean	7·0	4·5	6·8	5·2	3·5	2·5
SEM	0·7	0·3	0·2	0·2	0·1	0·2

* For details, see p. 3 and Table 2.

N excretion and correction of heat production for protein metabolism

Values for the urinary excretions of total N, urea and creatinine are given in Table 3. As expected, the N excretion was greatest for the Protein diet, while the low value for the Glucose diet reflected its low protein content. Changes in total N were accounted for largely by changes in urea excretion although there was also a significant increase in creatinine excretion on the Protein diet.

Using the individual values for N excretion, corrections were made to the estimates of heat production for the 24 h starting at 13.30 hours on day 1, and for three major time-periods within the 24 h. The small discrepancies between the periods for urine collections and those for heat production arose because of various practical constraints such as the separation of a urine collection from eating a meal.

A comparison between the corrected and uncorrected values for heat production showed that if no correction had been made for protein metabolism then the mean percentages by which heat production would have been over-estimated were 2·9 (SEM 0·13) and 0·8 (SEM 0·03) for the Protein and Glucose diets respectively.

Table 4. *Influence of nutrient composition on 24 h energy expenditure (kJ) measured by indirect and direct calorimetry*
(24 h was the period from 13.30 hours on day 1 to 13.30 hours on day 2)

Treatment†...	Protein			Glucose			Protein *v.* Glucose*	
Estimate of energy expenditure...							Average energy expenditure	
Subject no.	Heat Production	Heat Loss	Average	Heat Production	Heat Loss	Average	Difference	Percentage increase
1	9118	9219	9168	8062	8061	8062	+1107	+13·7
2	9264	9335	9300	8636	8498	8567	+733	+8·6
3	7888	7865	7876	6954	6854	6904	+973	+14·1
4	8177	8127	8152	7316	7163	7240	+913	+12·6
5	8577	8621	8599	8060	8068	8064	+535	+6·6
6	8798	8919	8858	7686	7457	7572	+1287	+17·0
Mean	8637	8681	8659	7786	7684	7735	+925	+12·1
SEM	218	242	230	245	256	250	109	1·6

* Statistical significance of the difference: $P < 0{\cdot}001$.
† For details, see p. 3 and Table 2.

Comparison between two independent estimates of 24 h energy expenditure

The two independent estimates of energy expenditure, derived indirectly from gaseous exchange and directly from EHL and SHL, agreed well. Table 4 gives individual values for each subject for both estimates of energy expenditure. A mean value for energy expenditure was calculated from heat production and heat loss; the difference between the two estimates was then expressed as a percentage of this mean:

$$\frac{(\text{Heat production} - \text{Heat loss})}{(\text{Heat production} + \text{Heat loss})/2} \times 100.$$

The percentage mean differences for the 24 h period in the calorimeter were only −0·5 (SEM 0·3) and +1·4 (SEM 0·5) for the Protein and Glucose treatments respectively. These findings indicate a close agreement between the two estimates of 24 h energy expenditure and, as previously discussed (Dauncey, 1980), it would be wrong to ascribe greater accuracy to either one of the two estimates.

Influence of nutrient composition on 24 h energy expenditure

Table 4 shows that altering the protein and carbohydrate composition of the diet for only 1 d, while maintaining constant its fat content and energy value, significantly influenced the 24 h energy expenditure ($P < 0{\cdot}001$). On average, energy expenditure was 12% greater for the Protein than for the Glucose treatment in the calorimeter, with the range for the six subjects being from 7 to 17%.

The individual values for the evaporative and sensible components of total heat loss are presented in Table 5. The mean values for both EHL and SHL were significantly greater on the Protein diet than on the Glucose diet ($P < 0{\cdot}025$). For the Glucose diet, total heat loss was made up of EHL 22% and SHL 78%. When the same six subjects were eating the Protein diet, the corresponding values were EHL 26% and SHL 74%.

The 13% mean increase in total heat loss on the Protein treatment was accounted for by mean increases of 39 and 7% for EHL and SHL respectively. These findings are in accord with the subjects being within their zone of thermal neutrality while on the Glucose diet. The extra production of heat on the Protein diet moved the subjects above thermal neutrality, to the area where heat is dissipated mainly by evaporation. A number of subjects commented on how they felt warmer in the calorimeter during the Protein session. Indeed, one subject surmized that the purpose of the investigation was really to study the effect of altering the temperature inside the calorimeter.

Energy expenditure during the daytime and night

Fig. 1 illustrates the response of one of the subjects to the Protein and Glucose treatments. It shows the half-hourly values of heat production for both sessions in the calorimeter. Also indicated is the pattern of activity carried out by all the subjects while occupying the calorimeter.

The mean and SEM values for the rate of energy expenditure per hour during the first day, night and second day are given in Fig. 2. Total heat loss is shown divided into its SHL and EHL components. For the illustration, individual variation between the subjects has been reduced by expressing the values as kJ/m^2 surface area. Preliminary calculations had shown that the coefficient of variation was smallest when the values were calculated on a surface area basis rather than as total kJ, kJ/kg body-weight, kJ/kg fat-free mass or kJ/kg body-weight$^{0{\cdot}75}$.

Fig. 2 shows that energy expenditure was higher on the Protein than on the Glucose treatment not only during the daytime but also at night ($P < 0{\cdot}001$). This finding clearly

Table 5. *Influence of nutrient composition on the evaporative and sensible components of 24 h heat loss (kJ)*

(24 h was the period from 13.30 hours on day 1 to 13.30 hours on day 2)

	Evaporative heat loss				Sensible heat loss			
Treatment†...	Protein	Glucose	Protein *v.* Glucose*		Protein	Glucose	Protein *v.* Glucose*	
Subject no.			Difference	Percentage increase			Difference	Percentage increase
1	2457	1817	+640	+35·2	6762	6244	+518	+8·3
2	2672	1758	+914	+52·0	6663	6740	−77	−1·1
3	2011	1366	+645	+47·2	5854	5488	+366	+6·7
4	2073	1444	+629	+43·6	6054	5719	+335	+5·9
5	1939	2064	−125	−6·1	6682	6004	+678	+11·3
6	2213	1489	+724	+48·6	6706	5968	+738	+12·4
Mean	2228	1656	+571	+38·8	6454	6027	+426	+7·2
SEM	116	110	146	7·0	161	178	120	2·0

* Statistical significance of the differences: $P < 0{\cdot}025$.

† For details, see p. 3 and Table 2.

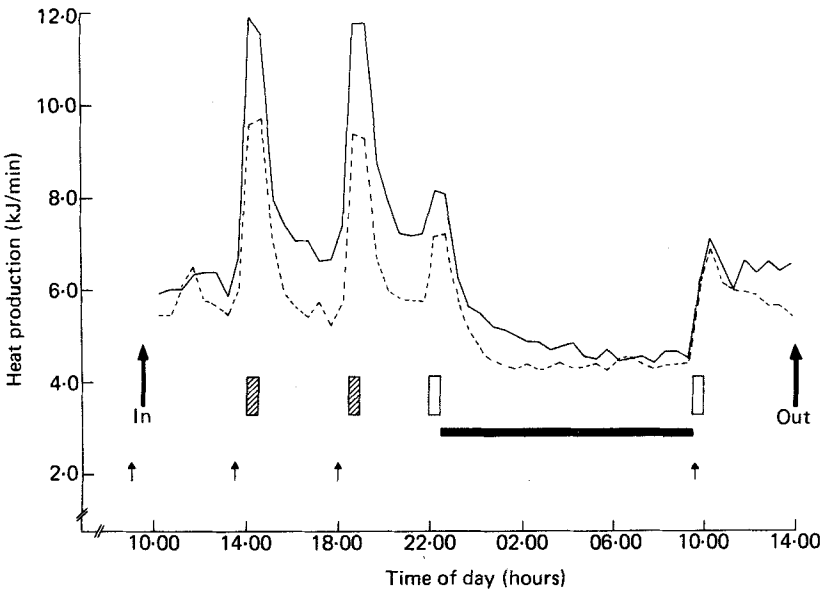

Fig. 1. Influence of nutrient composition on energy expenditure during a 24 h period. Half-hourly values of heat production (kJ/min) are shown for subject no. 1 on the Protein (——) and Glucose (----) diets. Total energy intakes were identical for the two sessions in the calorimeter, with a 24 h metabolizable energy intake of 10·3 MJ. The percentages of this energy supplied by protein and carbohydrate were 37 and 15% for the Protein diet and 3 and 49% for the Glucose diet (for details of diets, see p. 3 and Table 2). Meals (↑) were identical for any one session. The two sessions were separated by an interval of 1 month and took place at an ambient temperature of 26°. A predetermined pattern of activity was followed in the calorimeter: the subject cycled (▨) at 5 N and 50 rev./min for two 30 min periods, and stood (□) for two 30 min periods. Otherwise, the subject remained seated during the daytime and was able to read, write, listen to the radio or watch television. At night-time the subject slept (■) on a canvas bed.

indicated the extent to which nutrient composition could influence metabolic rate for many hours after the end of a meal. This 'carry-over' effect also explains why the difference between the two treatments was not as great on the second day, since the subject remained in the calorimeter for only 4 h after the meal on day 2. It was also found that for each of the three time-periods there was a greater proportional increase in EHL than in SHL on the Protein compared with the Glucose treatment. For both treatments, the rate of energy expenditure was greater on the first than on the second day simply because of the two 30 min periods of cycling on the ergometer.

DISCUSSION

In the present investigation the differences in protein and carbohydrate intake were large, and the extent to which smaller differences influence 24 h energy expenditure remains to be established. Nevertheless, the present findings indicate that not only should total energy intake (Dauncey, 1980) and environmental temperature (Dauncey, 1981) be considered as factors which can have small but potentially significant influences on energy balance in adult man, but also that the nutrient composition of the energy eaten should be considered in this category. Thus, although the absolute influences of each of these factors may be relatively small during a period of only 1 d, in terms of the prevention, development and treatment of obesity over several months or years, they cannot be ignored. Further, it is also recognized

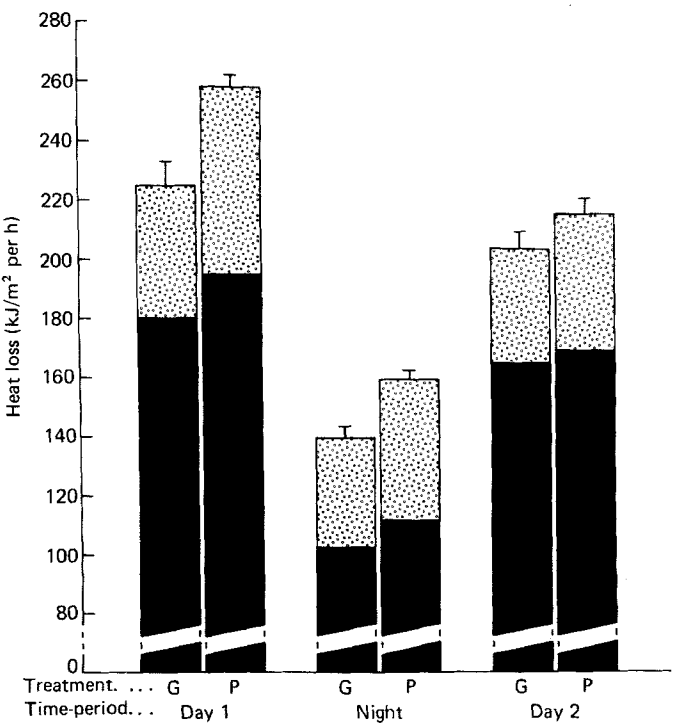

Fig. 2. Energy expenditure during the first day (13.30–22·30 hours), night (22.30–09.30 hours) and second day (09.30–13.30 hours). Mean values with their standard errors are given for total heat loss (kJ/m² per h) divided into its sensible (■) and evaporative (▨) components, for six subjects on high-glucose–low-protein (G) and high-protein–low-carbohydrate (P) intakes (for details of diets, see p. 3 and Table 2). For each subject the two treatments were separated by an interval of 1 month and the order was randomized. In a comparison of the Glucose and Protein treatments, paired *t* tests gave the following results: day 1, $P < 0{\cdot}005$; night, $P < 0{\cdot}001$; day 2, $P < 0{\cdot}01$.

that the problem of obesity is not uncommon in farm animals (Blaxter, 1975) and household pets (Mason, 1970).

The literature gives a wide range of opinions on the extent to which nutrient composition can influence metabolic rate. The fact that all nutrients increase metabolic rate, although by differing amounts, was acknowledged earlier this century by a number of workers (e.g. Rubner, 1902; Dubois, 1927; Lusk, 1928). In general, protein was found to have a greater effect than carbohydrate. The awareness that it was not only protein that increased metabolic rate was shown by Rubner (1902) in coining the phrase 'specific dynamic effect' to describe the increase in metabolic rate which follows food intake, and by Lusk (1928) in mentioning 'the erroneous idea that sugar exerted little or no specific dynamic action'. By contrast with the earlier findings this century, the suggestion was made by two groups of workers in the 1970s (Garrow & Hawes, 1972; Rosenberg & Durnin, 1978) that different nutrients have similar effects on metabolic rate. Thus, Garrow & Hawes (1972) said 'it is open to doubt whether anyone has shown in vivo a greater effect on resting metabolic rate of protein rather than carbohydrate or fat'. However, this conclusion was based on a study, in the first two parts of which there was only one subject, while in the third part their Fig. 2 shows that O_2 consumption was greater after a gelatin than a sucrose meal in four out of the five subjects. The conclusion of Rosenberg & Durnin (1978), that 'the so-called "specific dynamic action" may be a function of energy intake, independent of nutrient

intake' was based only on comparisons between iso-energetic meals with or without alcohol. Their conclusion is therefore relevant to alcohol alone. In summary, the relatively recent doubts about whether nutrient composition can alter metabolic rate have been based largely on studies in which the number of subjects was limited to one or where alcohol was the only nutrient to receive attention.

The present finding agrees in general with the earlier work this century and with that of Pittet *et al.* (1974), that amino acids influence metabolism to a greater extent than does glucose. Many factors influence the extent to which a particular nutrient affects metabolic rate. The methods used for estimating metabolic rate vary widely between investigations. For example, Rubner's (1902) findings were based on estimates of CO_2 production and N and carbon excretions, while Lusk (see Williams, 1912) measured both O_2 consumption and CO_2 production in a whole-body calorimeter. The extent to which environmental temperature, previous nutritional history and activity have been controlled varies between studies. For example, Rubner (1902) did not take account of muscular activity, whereas Williams *et al.* (1912) 'at the urgent suggestion of Dr F. G. Benedict' used 'a useful device for registering the movements of the dog'. The temperature of their calorimeter was maintained at 26–27° and only those results in which there was no movement were used for calculating the results.

The time over which the measurements are made influences the results. At the two extremes, Pittet *et al.* (1974) measured energy expenditure during the 2·5 h following a meal, while in the present study measurements were continued over a 24 h period. Glickman *et al.* (1948) showed that iso-energetic meals of 4·2 MJ containing either 37 or 7% of the energy as protein had similar influences on metabolic rate during the first hour of measurement. By 6·5 h after the meal the extra amounts of energy produced above the basal level were 548 and 357 kJ for the high-protein and high-carbohydrate diets respectively: values equivalent to 13·0 and 8·5% above the basal metabolic rate. Over the entire post-absorptive periods, estimated at 16 and 12 h for the protein and carbohydrate diets, the over-all 'specific dynamic actions' were found to be 17 and 10%. A similar influence of time has been shown in the present investigation.

Values for 'specific dynamic effect' are often stated broadly in terms of '100 kcal protein increase the heat production by x%'. Such a statement can be virtually meaningless if not also qualified by stating (*a*) the experimental conditions; (*b*) the species, age and sex of the subjects; (*c*) whether the percentage is calculated in relation to the 'basal metabolic rate' or the energy intake (Kleiber, 1975) and the conditions under which the 'basal' measurements are made (Dauncey, 1979*b*); (*d*) the total energy and nutrient intakes; and (*e*) the state of energy balance of the individual. With regard to (*d*), for example, the 'high'-protein intake used by Glickman *et al.* (1948) was 37% of the total energy, whereas the 'high'-protein value used by Miller & Mumford (1967) was 15% of the total energy. With reference to point (*e*), Blaxter (1971) has shown that the efficiency of utilization of a nutrient increases when the energy intake is below 'maintenance' and vice versa. It then becomes important to know that in one of Rubner's (1902) studies with a small dog, meat was fed at above the 'fasting requirement' whereas sugar was fed at a level below this requirement. In the present investigation the subjects were in positive energy balance; a further study would be needed to determine the extent to which metabolic rate might have been altered under conditions of negative energy balance.

There have been many attempts to explain the 'specific dynamic effect' of nutrients. For example, Borsook (1936) suggested that it was a composite of two factors: one concerned with N and the other with the metabolism of C. More recently, Blaxter (1971) has indicated possible reasons for the effect of protein being greater than that of glucose. These include the hypothesis that nutrients replace one another in relation to the amount of free energy

they provide which can be used in endergonic processes in the body. They are again dependent on whether the subject is above or below 'maintenance'. Krebs (1964) suggested that the extra heat production was attributable to energy requirements for urea synthesis and also to the wasting of some of the energy of amino acid degradation. The present investigation undoubtedly shows a close correlation between heat production and urea excretion, indicating that urea synthesis accounts for part of the extra heat production. However, Ashworth (1969) has shown that in rapidly-growing children recovering from malnutrition, there is also an energy cost for protein synthesis. It appears that the additional cost of protein turnover increases heat production; Coulson & Hernandez (1979) have shown that in alligators, peptide-bond synthesis seems to have been responsible for the three-fold increase in metabolic rate after feeding protein.

Finally, no one investigation can be considered ideal and conclusions must be made on the basis of many different investigations by different authors. Lusk (1928) recognized this and wrote of Rubner's (1902) results: 'They should not be quoted as infallible, though they are frequently so quoted'. More recently Kleiber (1975) has written the following in relation to the thermic effect of food: 'Forming hypotheses is one of the most precious faculties of the human mind... Sometimes, however, hypotheses grow like weeds and lead to confusion instead of clarification'.

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