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Influence of mild cold on 24 h energy expenditure, resting metabolism and diet-induced thermogenesis

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1. It has been suggested previously that people in developed countries do not expose themselves to cold severe enough to induce a metabolic response. The energy expenditure, as both heat production and total heat loss, of nine women was therefore measured continuously while each lived for 30 h in a whole-body calorimeter on two occasions, one at 28° and the other at 22°. All subjects followed a predetermined pattern of activity and food intake. The environmental conditions were judged by the subjects to be within those encountered in everyday life. In the standard clothing worn, 28° was considered to be comfortably warm but not too hot, while 22° was judged to be cool but not too cold.

2. Heat production for 24 h was significantly greater at the lower temperature, by (mean ± SE) 7·0 ± 1·1%. The range was between 2 and 12%. Total heat loss was also significantly greater, by 6%, and there was a large change in the partition of heat loss. At the lower temperature sensible heat loss increased by 29% while evaporative heat loss decreased by 39%.

3. Resting metabolism measured in the morning 12–13 h after the last meal was significantly greater at 22° than at 28°, whereas there was no difference when the resting measurement was made for 2·5 h following a meal.

4. In conclusion: (*a*) environmental temperature may play a more important role than was previously recognized in the energy balance of those living in this country, and (*b*) there is an indication of at least a partial replacement of cold-induced by diet-induced thermogenesis in man.

Metabolic rate increases in man as in other mammals during acute exposure to severe cold (Burton & Edholm, 1955; Horvath *et al.* 1956; Cannon & Keatinge, 1960; Buskirk *et al.* 1963; LeBlanc, 1975; Close *et al.* 1980). Although true cold exposure may sometimes occur at night in Australian aborigines (Scholander, Hammel, Hart *et al.* 1958) and Kalahari Bushmen (Wyndham & Morrison, 1958), clothes and central heating reduce considerably the extent to which a person is exposed to cold. Very little is known about the extent to which 24 h energy expenditure may be affected by the mild cold often experienced during normal living conditions in this country.

The present study has therefore investigated whether mild cold has any effect on the energy expenditure of women living for 30 h in a whole-body calorimeter, on two separate occasions. Environmental conditions were chosen to be within the range often encountered in this country. Standard clothing was worn, and the upper temperature (28°) was comfortably warm while the lower temperature (22°) was judged to be typical of the level at which people often live without any obvious signs of shivering.

An additional problem investigated was the possible interaction between the thermogenesis induced by cold and that due to diet. Evidence on this topic in man in inconclusive. Studies have usually been made in severe cold, when the effect of temperature on metabolic rate has been considerably greater than the effect of energy intake (Buskirk *et al.* 1960; Rochelle & Horvath, 1969).

A preliminary account of part of this work has been published (Dauncey, 1979*a;* James *et al.* 1979).

METHODS

Subjects

Nine women volunteered to take part in the investigation. They were all accustomed to laboratory surroundings and were familiarized with the calorimetry equipment before

Table 1. *Physical characteristics of subjects*

Subject no.	Age (years)	Height (m)	Wt (kg)	SA* (m²)	Fat† (%)	Difference between actual and 'ideal' weight-for-height‡ (%)
1	27	1·61	47·6	1·48	13·6	−13·3
2	23	1·61	67·2	1·71	27·9	+22·3
3	33	1·75	64·2	1·78	24·3	−0·6
4	35	1·69	64·3	1·74	22·5	+6·3
5	29	1·67	53·4	1·59	18·1	−9·0
6	38	1·65	56·1	1·61	20·8	−2·1
7	58	1·61	56·8	1·59	24·8	+3·4
8	24	1·62	51·3	1·53	18·8	−7·5
9	22	1·60	53·4	1·55	22·2	−0·9
Mean	32	1·64	57·1	1·62	21·5	−0·2
SE	4	0·02	2·2	0·03	1·4	3·5

SA, surface area.

* Calculated from DuBois & DuBois (1916).

† Fat as a percentage of body-weight from the sum of four skinfold thicknesses (Durnin & Womersley, 1974).

‡ From Metropolitan Life Insurance Company (1960).

taking part in the study. All the subjects were in apparently good health and none of them smoked. The mean age of the subjects was 32 years, body fat was 22% of the total body-weight and on average there was no difference between the actual and the 'ideal' weight-for-height (Table 1). However, there were reasonably wide variations in the age and other physical characteristics of the subjects, indicating that any results would not be applicable to just one small section of women in the population.

The investigation was approved by those individuals who became part of the newly-formed MRC Dunn Nutritional Laboratory Ethical Committee.

Experimental procedure

Each subject lived in the calorimeter for 30 h on two occasions, on one occasion at an ambient temperature of 28° and on the other at 22°. The two occasions were separated by 1 month, so that any effect of the monthly variation in metabolic rate was minimized (Aschoff & Heise, 1972). For five of the subjects the first session was at 28° while for the other four it was at 22°. The subjects were asked to ensure that the food and exercise taken on the day before entry into the calorimeter were the same on each occasion.

Ambient temperature and clothing. The investigation was being made in order to determine whether the mild cold often experienced in everyday life could affect the 24 h energy expenditure. The only clothing worn in the calorimeter was a trouser-suit made of thin cotton (see Dauncey, 1979*b*). The environmental temperatures were chosen on the basis of preliminary studies to represent the range which was usually tolerated by the subjects in everyday life without an alteration of clothing or external heating. Preliminary work had shown that 28° produced an effect equivalent to that experienced on a warm summer day, when sweating in women is not excessive. It was also found that 22° was equivalent to the lowest temperature at which most subjects could live in comfort and when there was no visible shivering or sensation of shivering, although piloerection would occur occasionally. The subjective feelings with regard to temperature were expected to alter during a 24 h period, but it was not possible to alter the temperature of the calorimeter with enough speed to cope with this problem.

Activity. The subject lived in the calorimeter from 09.30 hours on day 1 until 15.30 hours on day 2, during which time a predetermined pattern of activity was followed. From the start until 12.00 hours on day 2, the pattern of activity was designed to simulate a sedentary life-style and it was standardized so that the results could not be affected by major differences in physical activity. There were three 30 min periods of standing and one 30 min period of cycling at the low work load of 5 N and 25 rev/min. The subject spent the rest of the day-time sitting, during which time she was able to read, write, use the telephone, listen to the radio or watch television. A record of all such activities was kept by the subject during the first session, so that it was possible to carry out similar activities during the second session in the calorimeter. Subjective comments about the diet and ambient temperature were recorded when the subject came out of the calorimeter.

At night the subject lay on a canvas folding-bed and slept for most of the time between 22.30 and 07.30 hours. A pillow and two cotton sheets were used for bedding. Standard measurements of resting metabolism were made on day 2 at 07.30 – 08.30 hours and again at 12.30 – 15.30 hours.

An essential feature of the study was that the activity carried out by a subject at any particular time during the 30 h in the calorimeter was the same for both environmental temperatures. A direct comparison of the metabolic rate at 28° and that at 22° could therefore be made at any time of the day. The pattern of activity in the calorimeter is indicated in Fig. 1.

Resting metabolic rate. The two standardized measurements of resting metabolism were made to determine (*a*) the effect of mild cold on resting metabolic rate at least 12 h after the last meal, and (*b*) the relative effects of diet and mild cold on resting metabolic rate.

For the first measurement (*a*) the observer woke the subject at 07.30 hours by switching on the lights outside the calorimeter windows and buzzing on an intercom. The subject had been instructed previously to lie quietly awake on her back for the following hour. During this time she did not read or use the telephone and even small movements of the limbs were kept to a minimum. The subject could be seen through the windows of the calorimeter and outer room and the intercom was buzzed at frequent intervals to ensure that she did not fall asleep.

The second standard measurement of resting metabolism (*b*) was started after the mid-day meal on day 2. The meal, of 2615 kJ, was consumed within 10 min and the subject was lying on the bed by 12.15 hours, using one pillow for bedding. To allow time for the measurements to stabilize, on account of both the activity involved in moving from sitting to lying and the lag time of the system, the 3 h measurement was taken from 12.30 hours. The subject lay quietly throughout the period and the procedure was the same as that used for the fasting measurement.

Diet. A meal of 113 g Complan (Glaxo-Farley Foods Ltd, Plymouth, Devon) mixed with water, and 169 ml Lucozade (Beecham Products, Brentford, Middlesex) was taken by the subject at 08.30 hours on day 1. The meal was identical to the three other meals eaten during the day at 12.00, 16.00 and 19.00 hours. Each subject therefore ate 10·46 MJ within 24 h. The simple nature of the food allowed for accuracy in duplicating and speed of preparing the meals.

Measurement of energy expenditure

Heat production, evaporative heat loss and sensible heat loss were measured continuously while the subject was in the calorimeter. Full details of the techniques have been published (Dauncey & Murgatroyd, 1978; Dauncey *et al.* 1978). Heat production was calculated from the oxygen and carbon dioxide concentrations of the ingoing and exhaust air. Evaporative heat loss was determined from the wet-bulb and dry-bulb temperatures of the ingoing and outgoing air-streams, and sensible heat loss from the temperature difference across a water-cooled heat exchanger.

Table 2. 24 *h energy expenditure* (*total kJ*) *at* 28 *and* 22°, from 11.30 *hours on day* 1 *to* 11.30 *hours on day* 2

	Heat production (kJ)		Evaporative heat loss (kJ)		Sensible heat loss (kJ)	
Temperature (°) ... Subject no.	28	22	28	22	28	22
1	7350	7527	2271	1073	4964	6131
2	8061	8632	3022	1844	5078	6509
3	8406	9324	2913	2074	5350	7062
4	7985	8550	2524	1756	5455	6470
5	7529	7879	2617	1188	4976	6095
6	7973	8600	2739	1838	4872	6595
7	7481	7733	2884	1578	4510	6472
8	7063	7937	1825	1329	5206	6580
9	7599	8142	2347	1410	5038	6511
Mean	7716	8258	2571	1566	5050	6492
SE	139	188	126	112	92	94
Statistical significance of difference: *P*	< 0·001		< 0·001		< 0·001	

The paramagnetic and infra-red gas analysers were calibrated at 09.00 hours on the morning when the subject went in the calorimeter, and the wet-bulb wicks were renewed every week. Sensible heat loss calibrations using a standard heat input were made during the two nights before and after the subject lived in the calorimeter.

Analysis of results

All the parameters for estimating energy expenditure were monitored continuously on a chart recorder and stored on paper-tape at 5 min intervals, for computer analysis. Values of heat production and evaporative and sensible heat losses at 28° were compared with those at 22° using Student's paired *t* test.

RESULTS

24 h energy expenditure

The individual values of heat production, and evaporative and sensible heat losses between 11.30 hours on day 1 and 11.30 hours on day 2, at both 28 and 22°, are given in Table 2. To allow time for stabilization of the subject and equipment, values for the first 2 h in the calorimeter were not used. Mild cold caused a significant increase in 24 h energy expenditure ($P < 0·001$), with a mean (±SE) increase in heat production of 7 ± 1·1%, and a range of 2–12%. As a percentage of the total heat loss, the evaporative component was found to account for a mean (±SE) of 34 ± 1·3% and 19 ± 1·0% at 28° and 22° respectively. When the environmental temperature was reduced to 22° there was a mean (±SE) 6 ± 1·9% increase in the total heat loss. Furthermore, at the lower temperature evaporative heat loss decreased by 39 ± 3·4% while the sensible component increased by an average of 29 ± 2·5%.

There was a significant correlation between the 24 h heat production and a number of physical characteristics such as height, body-weight, lean body mass and body fat. This was the case at both environmental temperatures. However, although the taller and heavier subjects had the greater energy expenditure, the percentage increase in 24 h heat production in the cold was independent of body size and composition.

Energy expenditure during the day and night

The mean values of heat production, evaporative heat loss and sensible heat loss during the day-time and overnight are given in Table 3. The 24 h has been divided into three time periods: 11.30–22.30 hours on day 1, 22.30–08.30 hours while the subject was in bed, and 08.30–11.30 hours on day 2. It was found that not only was the heat production at 22° an average of 6% greater than that at 28° on day 1, but also that it remained elevated by 8% both overnight and during the following morning. These differences were all statistically significant, although there was again a wide range in the response of the individuals; during the day-time this was between -2 and $+20\%$, while at night it was between 0 and 22%. During each of the three time periods the changes in evaporative and sensible heat losses were highly significant ($P < 0{\cdot}001$).

Mean half-hourly values of heat production for both of the two sessions in the calorimeter are shown in Fig. 1. This illustrates the average response of the group to living at an ambient temperature of either 28 or 22° for a 30 h period. It should be noted that although the differences pointed out in Table 3 can be seen, there was very little difference in energy expenditure at 22° compared with 28° during the 30 min of cycling.

Resting metabolism

When the subjects were lying at rest from 07.30 to 08.30 hours, 12 to 13 h after the last meal, the heat production in the cold was significantly greater ($P < 0{\cdot}01$) by a mean (±SE) of $11 \pm 3{\cdot}2\%$ than that in the warm. This was despite the absence of any conscious shivering. Mean (±SE) values (kJ/min) were $4{\cdot}329 \pm 0{\cdot}152$ and $3{\cdot}899 \pm 0{\cdot}112$ at 22 and 28° respectively.

The resting metabolic rate measured later in the day at 12.30–15.30 hours was greater than that measured at 07.30 hours. This was to be expected, partly because of circadian variation and partly because of the food eaten after the first resting measurement in the morning. The important finding, however, was that the resting metabolism measured during the 2 h following a relatively small meal of 2·6 MJ was not significantly different at the two temperatures. This finding is illustrated in Fig. 2.

These results therefore indicated that at 22° the thermogenesis due to the meal at 12.00 hours replaced that caused by exposure to mild cold. The replacement may have been only partial since the resting metabolic rate during the 2 h after the meal at 28° was slightly less than that at 22°, even though the difference was not significant. Fig. 2 also shows that by the third hour after the mid-day meal the significant difference in metabolic rate at the two temperatures, which had been observed under fasting conditions, was again apparent. It was found that the partial replacement of cold-induced thermogenesis by that due to diet was seen only under the very carefully standardized conditions which were used at rest on day 2. The replacement was not obvious during the remainder of the time when the subject was living normally in the calorimeter, even though there was no difference in gross activity at the two ambient temperatures.

Subjective comments on ambient temperature

At both temperatures the subjective comments made by the individuals on the ambient temperature were dependent on the time of day. In general, most of the subjects found 28° to be comfortable for most of the time. Some people found it to be extremely comfortable throughout the time spent in the calorimeter while a few found it to be a bit too warm during parts of the day. Sweating for short periods was reported by a few individuals. At 22° the general comment was one of feeling cool and a bit chilly for parts of the time in the calorimeter. Occasionally piloerection was reported but the subjects appeared to be just above the threshold for shivering. On average the subjects slept well at 28° and not quite so well at 22°. At the lower temperature some of the subjects were awake for short periods of the night.

Table 3. *Energy expenditure (total kJ) during the first day, night and second day in the calorimeter, at* 28° *and* 22°

(Mean values with their standard errors of the mean, for nine subjects)

	Heat production (kJ)				Statistical significance of difference	Evaporative heat loss (kJ)				Statistical significance of difference	Sensible heat loss (kJ)				Statistical significance of difference
Temperature (°) . . .	28		22			28		22			28		22		
Time period*	Mean	SE	Mean	SE	*P*	Mean	SE	Mean	SE	*P*	Mean	SE	Mean	SE	*P*
Day 1 (11 h)	4115	68	4371	73	< 0·005	1362	73	796	59	< 0·001	2662	35	3469	35	< 0·001
Night (10 h)	2537	66	2738	107	< 0·02	883	51	566	45	< 0·001	1660	54	2077	63	< 0·001
Day 2 (3 h)	1064	28	1150	23	< 0·01	326	16	203	12	< 0·001	728	19	945	18	< 0·001

* Day 1, 11.30–22.30 hours; night, 22.30 hours on day 1–08.30 hours on day 2; day 2, 08.30–11.30 hours.

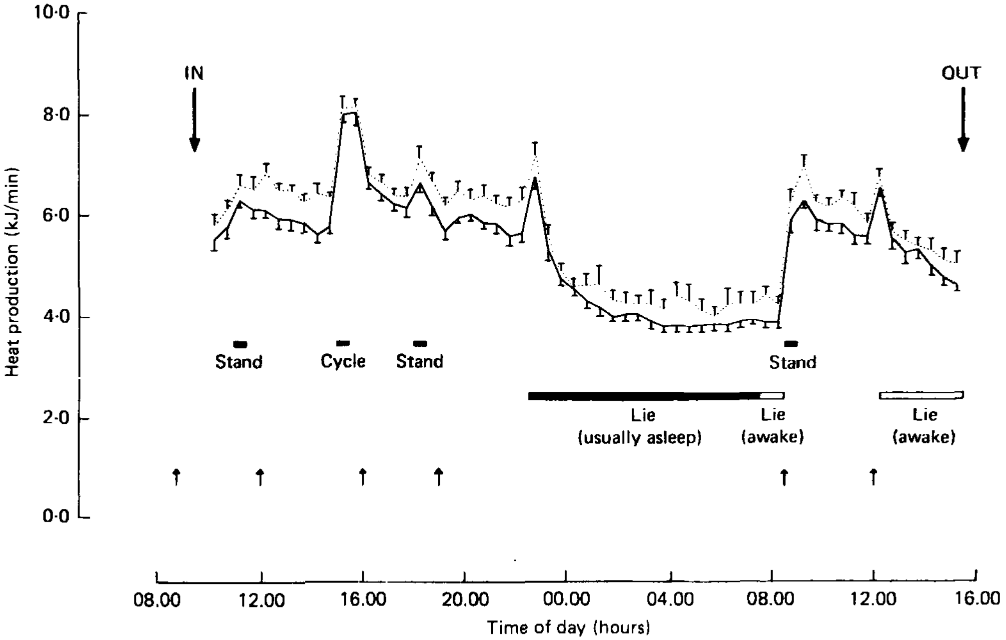

Fig. 1. Effect of mild cold on energy expenditure during two sessions of 30 h in the calorimeter. Ambient temperatures were within the zone of thermal neutrality, 28° (——), or equivalent to the mild cold often experienced in everyday life, 22° (···); standard clothing was worn. Sessions were at monthly intervals and each meal was identical and contained 2·6 MJ. A predetermined activity pattern was followed: the subject stood for three 30 min periods and cycled for 30 min at 5 N and 25 rev/min. Otherwise, the subject remained seated and was able to read, write, listen to the radio or watch television. The subject slept for most of the night, and lay awake for the two measurements of resting metabolism (□); see p. 4 and Fig. 2 for details. Mean values with their standard errors represented by vertical bars (*n* 9) for heat production (kJ/min) for each 30 min period are plotted. Because of the time lag of the system, peaks of heat production are recorded after the corresponding activity. Thus the high metabolic rate associated with moving the position of the furniture and preparing to go to bed appears on the graph at the start of the period of lying. ↑, meal.

The environmental conditions were representative of the range which all the subjects said they commonly experienced in everyday life. In general, however, the normal range tended to be wider, since the subjects had often felt considerably hotter or colder when living their normal life than when in the calorimeter at 28 or 22°.

DISCUSSION

An increase in 24 h energy expenditure occurred in this investigation when the ambient temperature was reduced by only 6°, from 28 to 22°. In women aged between 22 and 58 years, with a reasonably normal body-weight and body composition, heat production in the mild cold increased by an average of 7%, with a range of 2–12%. The upper temperature of 28° in the calorimeter was within the zone of thermal neutrality, although in some instances it was above the zone of pure vasomotor control and into the zone of evaporative control. The lower temperature felt cool, but it was not low enough to cause shivering. An essential point is that all the subjects had often tolerated colder conditions in everyday life than those in the calorimeter at 22°; reasons for this included being in a situation where the heating could not be turned up or where there were no more clothes available, or because of fashion.

There is virtually no published work for direct comparison with the present results. Most studies on the response to cold have been concerned with acute or chronic exposure to low

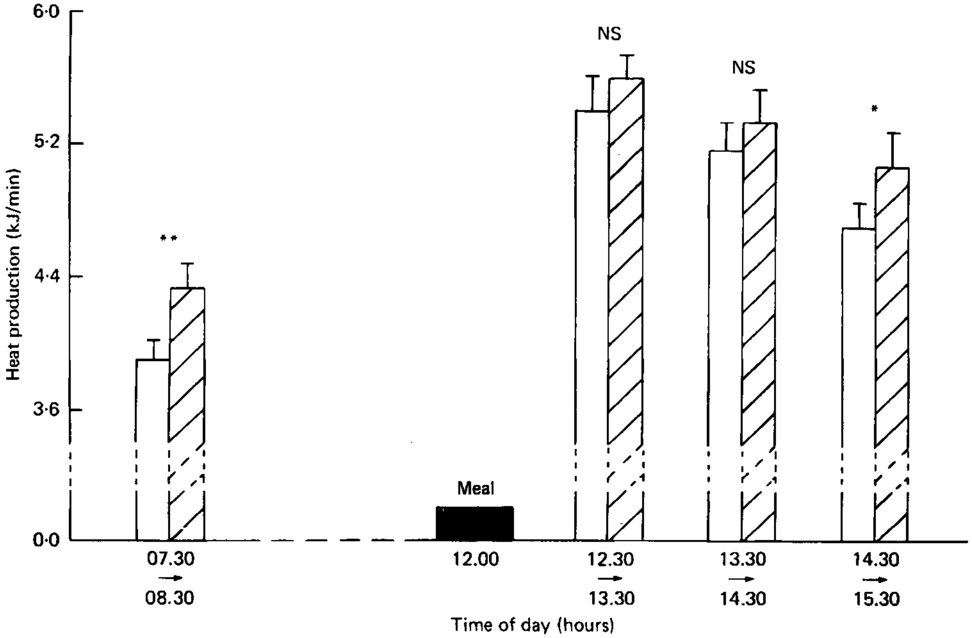

Fig. 2. Relative effects of mild cold and diet on resting metabolism. Measurements were made at thermal neutrality, 28° (□), and at 22° (▨) which was equivalent to the mild cold often experienced in this country; standard clothing was worn. Measurements were made on the second day in the calorimeter (see p. 4 for details); that in the morning was started 12 h after the last meal; those in the afternoon were made after a meal of 2·6 MJ. Mean values + 1 SE, represented by vertical bars (*n* 9) for heat production (kJ/min) for each hour are given. In a comparison of 28° with 22°: * $P < 0{\cdot}01$; ** $P < 0{\cdot}001$; NS, not significant.

temperatures which are expected to induce shivering. Additionally, the diet has not always been standardized and measurements of metabolic rate have often been made for only short periods of rest, due to the lack of suitable equipment.

Several ways by which the energy expenditure increased in the mild cold in the calorimeter can be postulated. Behavioural mechanisms cannot be excluded; the pattern of activity was standardized, but there may have been small differences in both movement and muscle tone between the two sessions. The physiological responses to cold depend on the extent and length of cold exposure and the amount of external insulation. Depending on the combination of these factors, the individual has the capacity for cutaneous vasoconstriction, a reduction in core temperature or an increase in metabolism by shivering and non-shivering mechanisms. The insulative cooling response of those Australian aborigines who have been exposed to a life-time of cold nights (Hammel *et al.* 1959) differs from the metabolic compensation and greater peripheral heating, without a reduction in core temperature, developed by white Norwegians in the severe cold (Scholander, Hammel, Hart *et al.* 1958). After approximately one week the Norwegians felt warm and showed a further rise in heat production, a conspicuous part of which was shivering. These subjects were soon able to sleep while shivering (Scholander, Hammel, Anderson *et al.* 1958), and Buguet *et al.* (1976) also suggested that shivering can occur during sleep in the cold. By contrast, Kreider & Iampietro (1959) found no evidence for this and their subjects allowed a decrease in skin and rectal temperatures. However, the findings of Buguet *et al.* (1976) and Kreider & Iampietro (1959) are not necessarily incompatible, since Irving *et al.* (1960) found that shivering could occur in 'light' but not 'deep' sleep.

In the present study all the subjects felt colder at 22° than at 28° and there must have been cutaneous vasoconstriction in parts of the body at some times of the day. Jéquier *et* *al.* (1974) studied eight women, aged approximately 24 years, at 20° for 2 h periods and found a tendency for heat production to rise when the mean skin temperature was below 30°. It is not certain whether this response would have been found in all the subjects in the present study; the metabolic response to cold exposure could be age-dependent since in another study those with a mean age of 64 years showed no significant increase in metabolism at 10° for 25 min whereas those of 25 years showed a significant increase of approximately 60% for the same exposure (Horvath *et al.* 1955). Those in the calorimeter showed no overt signs of shivering at 22°, since this temperature was chosen to be above the threshold for shivering. Nevertheless there were occasional signs of piloerection in a few subjects and the only way differences in muscular activity at rest could have been tested was with an electromyograph. It is highly likely that the use of an electromyograph and numerous temperature probes over 24 h would have severely restricted the 'normal' life-style of the subjects.

The major metabolic response in man to severe cold is shivering, but there is also the possibility of a limited capacity for non-shivering thermogenesis. Obvious shivering was excluded in the present investigation and the mild cold exposure may have resulted in an increase in the non-shivering component of thermogenesis alone. Another study, aimed at investigating heat production from shivering, coincidentally found evidence to support this suggestion (Iampietro *et al.* 1960). Subjective evaluation indicated that although there was no noticeable shivering at 21° and a windspeed of less than 1 km/h, and at 27° and 16 km/h, these same conditions gave small increases in heat production. Other workers have also provided evidence to implicate the participation of heat-producing mechanisms in the cold which do not involve shivering (Davies, 1963; Cipriano & Goldman, 1975; Blatteis & Lutherer, 1976).

A number of different mechanisms could account for non-shivering thermogenesis in the present study. Postulated mechanisms include sodium ion translocation, cycling of calcium ions (Stucki & Ineichen, 1974), glucose and fatty-acid-substrate cycles (Newsholme & Crabtree, 1976) and a proton short-circuit in brown adipose tissue (Nicholls, 1979). Brown adipose tissue is generally regarded as a major site of non-shivering thermogenesis in small mammals (Smith & Roberts, 1964; Kuroshima *et al.* 1967; Foster & Frydman, 1979; Thurlby & Trayhurn, 1980). Although the role of brown fat in large mammals is uncertain, small quantities have been found in adult man (Heaton, 1972; Tanuma *et al.* 1975) and evidence for its presence in another large mammal, the pig, has been reported recently (Dauncey *et al.* 1981). Catecholamines can alter energy expenditure in many ways, including the stimulation of heat-generating processes in brown adipose tissue (Smith, 1964; Bukowiecki *et al.* 1980). Both man and the pig show a similar increase in metabolic rate in response to noradrenaline (LeBlanc & Mount, 1968; Heath, 1978; Jung *et al.* 1979). Furthermore, plasma noradrenaline levels increase in the pig during short-term cold exposure (Ingram *et al.* 1979; Barrand *et al.* 1981), and an enhanced metabolic response to noradrenaline occurs in man after cold acclimatization (Joy, 1963; Itoh, 1974). Using ephedrine as a sympathomimetic agent, evidence has been presented to indicate a role for brown fat in this metabolic response to catecholamines in man (Rothwell & Stock, 1979).

Thermoregulatory thermogenesis was partially replaced by diet-induced thermogenesis under certain conditions in the present study, although activity tended to mask this effect. Rubner (1902) was the first to postulate 'chemical' as distinct from 'physical' regulation of cold-induced metabolism and found that food intake could cancel 'chemical' regulation either wholly or in part. His work with the dog indicated a replacement, either partial or complete, of cold-induced thermogenesis with that due to energy intake (Rubner, 1902; Lusk, 1928). A similar investigation in man failed to confirm Rubner's (1902) finding (Buskirk *et al.* 1960). However, the severe cold used in this later study probably masked the relatively small effect of the meal. The present findings and those of Rubner (1902) therefore support the suggestion that at least some of the mechanisms of thermogenesis induced by diet are similar to those due to cold (Stirling & Stock, 1968; Dauncey & Ingram, 1979; Rothwell & Stock, 1979).

Previously it was not known whether cold could play a role in the energy balance of those living in this country. One suggestion had indicated that, given the chance, people do not expose themselves to cold severe enough to induce a metabolic response, with the result that cold exposure need not even be considered as a factor which affects energy expenditure (Garrow, 1978). A detailed study on the effective temperatures to which a wide range of people expose themselves in everyday life has not yet been made. Nevertheless, all the subjects in the present study found that the cold conditions which led to an increase in metabolic rate in the calorimeter had often been exceeded in everyday life. This could be of relevance, since small changes in energy balance are important in the long-term maintenance of normal body-weight and the prevention of obesity. A theoretical calculation using the present results gives an indication of the potential long-term effect of mild cold on energy balance. Assuming other factors such as energy intake and external insulation to be equal, and that adipose tissue with an energy density of 25 MJ/kg is the major body component to be affected, then in 10 years, if these subjects had experienced mild cold for only 10% of each year they would have had, on average, an 8 kg loss in body-weight. At the two extremes, the subject showing an increase in 24 h energy expenditure of only 2% in the cold would have had a 3 kg decrease in body-weight, while the subject with a 12% increase in metabolism would theoretically have lost 13 kg.

To summarize, this investigation indicates that mild cold should at least be considered as a factor which can affect the energy metabolism of people living in this country. In Rubner's (1902) words, 'I do not consider it possible to separate nutritional science from the science of heat production in metabolism, as many are inclined to do. This can only hamper the understanding of the processes of life.'

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REFERENCES

Aschoff, J. & Heise, A. (1972). In *Advances in Climatic Physiology*, p. 334 [S. Itoh, K. Ogaka and H. Yoshimura, editors]. Tokyo: Igaku Shoin Ltd.

Barrand, M. A., Dauncey, M. J. & Ingram, D. L. (1981). *J. Physiol., Lond.* (In the Press).

Blatteis, C. M. & Lutherer, L. O. (1976). *J. appl. Physiol.* **41**, 848.

Buguet, A. G. C., Livingstone, S. D., Reed, L. D. & Limmer, R. E. (1976). *J. appl. Physiol.* **41**, 142.

Bukowiecki, L., Folléa, N., Paradis, A. & Collet, A. (1980). *Am. J. Physiol.* **238**, E552.

Burton, A. C. & Edholm, O. G. (1955). *Man in a Cold Environment*. London: Edward Arnold.

Buskirk, E. R., Thompson, R. H., Moore, R. & Whedon, G. D. (1960). *Am. J. clin. Nutr.* **8**, 602.

Buskirk, E. R., Thompson, R. H. & Whedon, G. D. (1963). *J. appl. Physiol.* **18**, 603.

Cannon, P. & Keatinge, W. R. (1960). *J. Physiol., Lond.* **154**, 329.

Cipriano, L. F. & Goldman, R. F. (1975). *J. appl. Physiol.* **39**, 796.

Close, W. H., Dauncey, M. J. & Ingram, D. L. (1980). *Br. J. Nutr.* **43**, 87.

Dauncey, M. J. (1979a). *J. hum. Nutr.* **33**, 259.

Dauncey, M. J. (1979b). *Nutr. Fd Sci.* **60**, 20.

Dauncey, M. J. & Ingram, D. L. (1979). *Br. J. Nutr.* **41**, 361.

Dauncey, M. J. & Murgatroyd, P. R. (1978). *J. Physiol., Lond.* **284**, 7p.

Dauncey, M. J., Murgatroyd, P. R. & Cole, T. J. (1978). *Br. J. Nutr.* **39**, 557.

Dauncey, M. J., Wooding, F. B. P. & Ingram, D. L. (1981). *Res. vet. Sci.* (In the Press).

Davies, T. R. A. (1963). *Fedn. Proc. Fedn. Am. Socs exp. Biol.* **22**, 777.

DuBois, D. & DuBois, E. F. (1916). *Archs intern. Med.* **17**, 836.

Durnin, J. V. G. A. & Womersley, J. (1974). *Br. J. Nutr.* **32**, 77.

Foster, D. O. & Frydman, M. L. (1979). *Can. J. Physiol. Pharmac.* **57**, 257.
Garrow, J. S. (1978). *Energy Balance and Obesity in Man*, 2nd ed. Amsterdam, New York and Oxford: Elsevier/North-Holland Biomedical Press.
Hammel, H. T., Elsner, R. W., Le Messurier, D. H., Andersen, H. T. & Milan, F. A. (1959). *J. appl. Physiol.* **14**, 605.
Heath, M. E. (1978). Morphological, physiological and behavioural differences of piglets reared in a cold or a hot environment. PhD Thesis, University of Cambridge.
Heaton, J. M. (1972). *J. Anat.* **112**, 35.
Horvath, S. M., Radcliffe, C. E., Hutt, B. K. & Spurr, G. B. (1955). *J. appl. Physiol.* **8**, 145.
Horvath, S. M., Spurr, G. B., Hutt, B. K. & Hamilton, L. H. (1956). *J. appl. Physiol.* **8**, 595.
Iampietro, P. F., Vaughan, J. A., Goldman, R. F., Kreider, M. B., Masucci, F. & Bass, D. E. (1960). *J. appl. Physiol.* **15**, 632.
Ingram, D. L., Dauncey, M. J., Barrand, M. A. & Callingham, B. A. (1979). In *Catecholamines and Stress*, p. 273 [E. Usdin, R. Kvetnansky, & I. J. Kopin, editors]. New York: Elsevier/North Holland Biomedical Press.
Irving, L., Andersen, D. L., Bolstad, A., Elsner, R., Hildes, J. A., Løyning, Y., Nelms, J. D., Peyton, L. J. & Whaley, R. D. (1960). *J. appl. Physiol.* **15**, 635.
Itoh, S. (1974). *Physiology of Cold-Adapted Man*, p. 55. Sapporo: Buneido.
James, W. P. T., Dauncey, M. J., Jung, R. T., Shetty, P. S. & Trayhurn, P. (1979). In *Genetic Models of Obesity in Laboratory Animals and in Man*, p. 221 [M. Festing, editor]. London: Macmillan.
Jéquier, E., Gygax, P.-H., Pittet, P. & Vannotti, A. (1974). *J. appl. Physiol.* **36**, 674.
Joy, R. J. T. (1963). *J. appl. Physiol.* **18**, 1209.
Jung, R. T., Shetty, P. S., James, W. P. T., Barrand, M. A. & Callingham, B. A. (1979). *Nature, Lond.* **279**, 322.
Kreider, M. B. & Iampietro, P. F. (1959). *J. appl. Physiol.* **14**, 765.
Kuroshima, A., Konno, N. & Itoh, S. (1967). *Jap. J. Physiol.* **17**, 523.
LeBlanc, J. (1975). *Man in the Cold.* Illinois: Charles C. Thomas.
LeBlanc, J. & Mount, L. E. (1968). *Nature, Lond.* **217**, 77.
Lusk, G. (1928). *The Elements of the Science of Nutrition*, 4th ed. Philadelphia and London: W. B. Saunders Co.
Metropolitan Life Insurance Company, New York (1960). *Stat. Bull.* **41**, February p. 6 and March p. 1.
Newsholme, E. A. & Crabtree, B. (1976). *Biochem. Soc. Symp.* **41**, 61.
Nicholls, D. G. (1979). *Biochim. biophys. Acta.* **549**, 1.
Rochelle, R. H. & Horvath, S. M. (1969). *J. appl. Physiol.* **27**, 710.
Rothwell, N. J. & Stock, M. J. (1979). *Nature, Lond.* **281**, 31.
Rubner, M. (1902). *Die Gesetze des Energieverbrauchs bei der Ernährung.* Leipzig und Wien: Franz Deuticke; translation into English by A. Markoff and A. Sandri-White [R. J. T. Joy, editor]. Natick, Massachusetts: United States Army Research Institute of Environmental Medicine.
Scholander, P. F., Hammel, H. T., Andersen, K. L. & Løyning, Y. (1958). *J. appl. Physiol.* **12**, 1.
Scholander, P. F., Hammel, H. T., Hart, J. S., Le Messurier, D. H. & Steen, J. (1958). *J. appl. Physiol.* **13**, 211.
Smith, R. E. (1964). *Science, N.Y.* **146**, 1686.
Smith, R. E. & Roberts, J. C. (1964). *Am. J. Physiol.* **206**, 143.
Stirling, J. L. & Stock, M. J. (1968). *Nature, Lond.* **220**, 801.
Stucki, J. W. & Ineichen, E. A. (1974). *Eur. J. Biochem.* **48**, 365.
Tanuma, Y., Yamamoto, M., Ito, T. & Yokochi, C. (1975). *Arch. histol. Jap.* **38**, 43.
Thurlby, P. L. & Trayhurn, P. (1980). *Pflügers Arch.* **385**, 193.
Wyndham, C. H. & Morrison, J. F. (1958). *J. appl. Physiol.* **13**, 219.

ADDENDUM

In *Br. J. Nutr.* (1979) Vol. **42**, 1 and (1980) **43**, 257 the settings in the bicycle ergometer should have been given as 10 N and 5 N not 1 N and 0·5 N.

In Vol. **43**, 265 under the heading 'RQ' the SEMs for the high and medium intakes should read 0·009 and 0·007, not 0·093 and 0·071.

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