Influence of mild cold on 24 h energy expenditure in 'normally' clothed adults

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Ten subjects aged 19–35 years (four men and six women) underwent two measurements of 24 h energy expenditure (EE) in a whole-body respiration calorimeter, one at a temperature of 28° and one at 20°. Choice of clothing was allowed. Dietary intake was standardized and subjects were asked to follow the same pattern of activity during both measurements. Mean 24 h EE was significantly greater at the cooler temperature by 5·0 (SD 5·5) %, with individual differences ranging from 4·6% lower to 12·6% higher. The difference in EE at the two temperatures was similar during the day and the night and occurred even though subjects wore more clothes and used more bedding at 20°. No relationship was observed between response to 20° and body-weight status. In conclusion, the assumption that mild cold is unlikely to affect EE in subjects wearing normal clothing may be incorrect.

Energy expenditure: Environmental temperature

It is well established that energy expenditure (EE) increases during acute exposure to severe cold (15° or less) and that this is largely due to shivering (Buskirk *et al.* 1960, 1963; Iampietro *et al.* 1960; Wyndham *et al.* 1968; Rochelle & Horvath, 1969; Bittel, 1987; Young *et al.* 1989). Mild cold also increases EE in lightly-clad subjects in the absence of shivering (Iampietro *et al.* 1960; Quaade, 1963; Dauncey, 1981; Blaza & Garrow, 1983). Several workers have suggested that cold exposure is of little practical importance as a factor affecting EE since effects of cold are minimized by adjustments to clothing or heating, or both (Food and Health Organization/World Health Organization/United Nations University, 1985; James, 1985) and if people are given the chance they do not expose themselves to cold severe enough to induce a metabolic response (Garrow, 1978). However, De Boer *et al.* (1988) found a lower EE in a group of normally clothed men housed in a calorimeter at 24·5° compared with another group measured at 21·0°, and postulated that mild cold might also affect subjects allowed to change clothes according to their perception of temperature. Since little is known about the effects of mild cold in 'normally' clothed subjects, the aim of the present study was to investigate whether mild cold increases 24 h EE in subjects confined in a respiration chamber and allowed to choose their own clothing.

METHODS

Subjects and protocol

Ten healthy subjects (six females, four males; all non-smokers) were recruited from university student and staff volunteers. All subjects underwent two measurements of 24 h EE in a whole-body respiration calorimeter, one at a temperature of 28° and one at 20°. The order of measurements was randomized. In women, the two measurements were done either 1 month apart or within the same week to minimize effects of the menstrual cycle. In men, both measurements were done within a 6-week period. All subjects were instructed to take a variety of clothing into the calorimeter to ensure a choice of 'normal' clothing at each temperature. Ample bedding was supplied. The amount of clothing worn and bedding used was recorded. Dietary intake was standardized and subjects were asked to follow the same pattern of activity during both measurements. Subjects were asked to ensure that their activity and dietary intake were similar during the day before each calorimetry measurement. The study protocol was approved by the Ethics Committee of this University.

Basal metabolic rate (BMR)

BMR was measured directly after each calorimetry measurement in a ventilated hood apparatus as described previously (Warwick *et al.* 1987). All measurements were done at least 12 h after the last meal, in a room held at a temperature of 25–28°.

Body-weight

Body-weight was measured directly after each calorimetry measurement using a beam balance capable of weighing to within 50 g. All measurements were made before breakfast, with an empty bladder and wearing similar clothes.

24 h EE

The 24 h EE was measured using a whole-body respiration calorimeter as described previously (Warwick *et al.* 1988), except that in the present study subjects were studied at ambient temperatures of 28° and 20°, and the following equation was used to calculate EE from gaseous exchange and urinary nitrogen excretion (Brockway, 1987):

$$\text{EE (kJ)} = 16{\cdot}58\ O_2\ \text{(litres)} + 4{\cdot}51\ CO_2\ \text{(litres)} - 5{\cdot}90\ \text{N (g)}.$$

Air velocity in the calorimeter was lower than 0·2 m/s with velocities of 0·18 m/s under the desk and 0·13 m/s on the bed (measured by anemometer). Relative humidity averaged 53% at 28° and 56% at 20° and varied between 40 and 60% at both temperatures. The function of the calorimeter was tested by combustion of ethanol and was found to be accurate to within 1·5% at both temperatures.

Eight subjects spent adaptive nights in the calorimeter (i.e. entered the calorimeter at 20.00 hours) with 24 h EE measurements commencing at 08.00 hours the next morning. Two subjects who were familiar with the calorimetry measurements arrived at the laboratory in time to enter the calorimeter at 08.00 hours

Dietary intake

Dietary intake during the 24 h EE measurements was calculated using food composition tables (Thomas & Corden, 1977) to provide a daily energy intake of about 1·27 times the BMR of each subject as measured before the start of the study. Diets provided on average 20, 26 and 54% of energy from protein, fat and carbohydrate respectively with a food quotient of 0·88. Meals were served at 08.00, 13.00 and 18.00 hours, with additional snacks if desired. Coffee and tea were allowed as desired. All subjects consumed the same diet (and coffee and tea) during both of the calorimetry measurements.

Level of activity

All subjects were asked to follow the same (self chosen) pattern of sedentary activities during each of the 24 h EE measurements, and to keep minute-by-minute activity records. Activities were grouped into the following categories and assigned a code: asleep, lying quietly, sitting quietly, sitting busy, and standing activities. Exercise was not allowed. Subjects were asked to be settled in bed by 23.00 hours and to stay lying quietly in bed until

Table 1. *Characteristics, basal metabolic rate (BMR) and treatment details of subjects*

Subject no.	Sex	Age (years)	Height (m)	Wt* (kg)		Body mass index†	BMR* (MJ/d)		Treatment details	
				28°	20°		28°	20°	First treatment	Season studied
1	♂	20	1·82	68·2	68·0	20·6	6·76	6·75	20°	Early spring
2	♂	25	1·76	68·0	67·9	21·9	7·66	7·93	28°	Early spring
3	♀	35	1·69	65·8	66·1	23·1	6·12	5·97	20°	Mid-spring
4	♀	19	1·64	66·6	66·5	24·7	5·80	5·49	20°	Late autumn
5	♀	19	1·69	66·8	66·5	23·3	6·66	6·48	28°	Mid-spring
6	♂	21	1·80	79·3	80·2	24·6	7·62	7·78	28°	Late summer
7	♀	21	1·66	77·4	77·5	28·1	6·20	6·60	20°	Early autumn
8	♀	22	1·65	112·3	112·3	41·2	7·44	7·33	28°	Early autumn
9	♀	20	1·67	101·0	100·0	36·0	7·49	7·83	20°	Late autumn
10	♂	29	1·78	103·8	102·7	32·6	9·32	9·04	28°	Late autumn
Mean	—	23·1	1·72	80·9	80·8	27·6	7·11	7·12	—	—
SD	—	5·2	0·07	17·9	17·7	6·8	1·03	1·11	—	—

* After 28° and 20° calorimetry measurements.
† Weight (kg)/height (m)^2.

called at 08.00 hours. Overall levels of activity were calculated as multiples of BMR from time periods spent in each activity category and their average energy costs as described previously (Warwick *et al.* 1988). The energy costs used in the present study were: asleep or lying quietly overnight (24.00–08.00 hours) 1·0 × BMR; asleep, lying or sitting quietly during the day and evening, 1·2 × BMR; sitting busy 1·5 × BMR; standing activities 2·5 × BMR.

Statistical analysis

All data manipulation and statistical analysis were done using the Minitab package (Ryan *et al.* 1985). Significance of differences was assessed by paired *t* tests.

RESULTS

The physical characteristics, BMR and treatment details of the subjects are shown in Table 1. Six subjects had a body mass index (BMI) in the range 20–25, one in the range 25–30, and three greater than 30. Body-weight was stable to within about 1 kg and mean body-weight was the same after both calorimetry measurements. Mean BMR was the same after the 28° and 20° measurements (7·11 (SD 1·03) and 7·12 (SD 1·11) MJ/d respectively) and after the first and second measurements (7·09 (SD 1·00) and 7·13 (SD 1·08) MJ/d respectively). Individual coefficients of variation for the two BMR measurements averaged 1·6 % (range 0·1–3·1 %).

Table 2 shows the individual and mean results for EE, energy intake, respiratory quotient (RQ) and activity level of each subject during the two calorimetry measurements. The 24 h EE results have also been expressed as multiples of mean BMR, and have been subdivided into overnight (24.00–08.00 hours) and daytime (08.00–24.00 hours) EE.

On average 24 h EE was 5 % higher during the 20° than the 28° measurement period ($P < 0·02$) with individual differences ranging from 4·6 % lower to 12·6 % higher. Daytime EE and overnight EE were also higher at 20° ($P < 0·05$). During the day, individual differences ranged from 7·7 % lower to 15·8 % higher at 20°, while overnight they ranged from 0·8 % lower to 8·9 % higher.

Table 2. *Energy expenditure (EE), energy intake, respiratory quotient (RQ) and activity level of normally clothed human subjects in a calorimeter at 28° and 20°*

Subject no.	24 h EE (MJ/d) 28°	24 h EE (MJ/d) 20°	24 h EE (MJ/d) % difference*	Energy intake† (MJ/d)	24 h RQ 28°	24 h RQ 20°	24 h EE:BMR 28°	24 h EE:BMR 20°	Activity level‡ 28°	Activity level‡ 20°	Daytime EE (MJ/16 h) 28°	Daytime EE (MJ/16 h) 20°	Overnight EE (MJ/8 h) 28°	Overnight EE (MJ/8 h) 20°
1	8·86	8·93	0·8	9·32	0·827	0·926	1·31	1·32	1·30	1·30	6·61	6·86	2·25	2·07
2	8·88	9·38	5·7	9·51	0·915	0·885	1·14	1·20	1·20	1·18	6·53	6·94	2·34	2·44
3	7·69	8·09	5·2	7·83	0·899	0·855	1·27	1·34	1·33	1·34	5·86	6·23	1·84	1·86
4	7·42	8·35	12·6	7·20	0·909	0·838	1·31	1·48	1·27	1·30	5·81	6·73	1·61	1·62
5	8·90	9·28	4·2	8·33	0·863	0·820	1·35	1·41	1·37	1·37	6·88	7·06	2·03	2·21
6	9·50	9·84	3·5	9·59	0·868	0·864	1·23	1·28	1·16	1·18	7·26	7·45	2·25	2·39
7	7·67	8·45	10·2	8·09	0·901	0·901	1·20	1·32	1·32	1·31	5·83	6·55	1·84	1·90
8	8·80	9·81	11·5	8·91	0·916	0·851	1·19	1·33	1·33	1·33	6·80	7·47	2·01	2·34
9	9·76	9·82	0·7	9·84	0·827	0·864	1·27	1·28	1·25	1·23	7·53	7·43	2·23	2·39
10	10·19	9·72	−4·6	10·57	0·896	0·901	1·11	1·06	1·19	1·15	7·51	6·93	2·69	2·79
Mean	8·77	9·17	5·0	8·92	0·882	0·874	1·24	1·30	1·27	1·27	6·67	6·97	2·11	2·20
SD	0·93	0·67	5·5	1·04	0·034	0·030	0·08	0·11	0·07	0·08	0·67	0·41	0·31	0·34
Statistical significance of difference: *P*	< 0·02		—	—	NS		< 0·02		NS		< 0·05		< 0·05	

BMR, basal metabolic rate; NS, not significant.
* Percentage difference in 24 h EE at the two temperatures calculated as 100 × (20° − 28°)/28°.
† Energy intake was the same at both temperatures.
‡ From activity records, expressed as multiples of BMR.

Table 3. *Temperature preference, clothing worn and bedding used by normally clothed human subjects during 28° and 20° measurements in the calorimeter*

Subject no.	Temperature preference	Clothing worn (daytime)*		Bedding used (at night)*	
		28°	20°	28°	20°
1	28°	s+t	Tr+4T	S (+B)	S+3B
2	28°	s+t	Tr+2T	S	S+2B
3	20°	s+t	Tr+3 4T	S (+C)	C+1B
4	28°	s+t	Tr+2T	S (+B)	S+3B
5	20°	s+t	Tr+2T	S	S+3–4B
6	20°	s+t	s+1T+B	S	S+1B
7	20°	s+t	Tr+2T	S (+C)	C
8	20°	s+t	Tr+2–3T	S	S+2–3B
9	28°	s+t	Tr+2T	S	S+3B
10	20°	s+t	Tr+1T	S	S+3B

* s+t, Light shorts or skirt (s) and t-shirt (t) with sandals; Tr, long trousers with shoes and socks; T, top garments; 1T, one garment; 2T, two garments, etc.; B, blanket; 1B, one blanket; 2B, two blankets etc.; (subject no. 6 wrapped a blanket around himself); S, sheet; C, continental quilt; (C) or (B), continental quilt or blanket used during part of the night only.

On average the group was slightly but not significantly in negative energy balance during the 20° measurement and in positive balance during the 28° measurement. RQ did not vary with temperature, averaging 0·882 (SD 0·03) and 0·874 (SD 0·03) over the 24 h. The mean 24 h RQ was similar to the food quotient of the dietary intake.

The mean 24 h EE: BMR ratio was 1·24 (SD 0·08) at 28° and 1·30 (SD 0·11) at 20° ($P < 0·02$), while the mean recorded activity level was 1·27 (SD 0·07–0·08) at both temperatures. On average, subjects spent 14 h lying quietly or asleep, 2·5 h sitting quietly, 6·5 h sitting busy and 1 h in standing activities. Only two subjects recorded different activity patterns between the two temperatures. Subject no. 4 was less active at 28°, spending 0·5 h less time on foot and 0·5 h more time lying quietly. Subject no. 10 was less active at 20°, spending 0·5 h less time on foot, 6·5 h less time sitting quietly and 7 h more time lying quietly or asleep during the day.

Table 3 shows the temperature preference of each subject and the clothing worn and bedding used at each temperature. Four subjects preferred 28° while six preferred 20°. All subjects wore more clothing and used more bedding at the cooler temperature. All subjects reported sleeping well during the overnight measurement except for subject no. 3 who felt too hot at 28°.

DISCUSSION

The present study has shown that 24 h EE in normally clothed subjects in a whole-body respiration calorimeter is significantly greater at an ambient temperature of 20° than at 28°. The increase in EE at 20° was similar during the day and the night and occurred even though all subjects wore more clothes and used more bedding than at 28°. The mean increase was small, only 5 %, but not necessarily negligible if considered as an additive effect on EE over a prolonged period of time. These results call into question the assumption that mild cold is unlikely to affect EE in subjects kept insulated by clothing or blankets (Food and Agriculture Organization/World Health Organization/United Nations University, 1985; Warwick *et al.* 1987).

There are few other studies of effects of mild cold on 24 h EE with which to compare our results. De Boer *et al.* (1988) noted a lower 24 h EE in a group of normally clothed men housed in a calorimeter at 24·5° compared with another group housed at 21°, although their study was not designed to investigate effects of temperature. Dauncey (1981) observed a 7% increase in 24 h EE in nine lightly-clad, normal-weight women at a temperature of 22° compared with 28°. Blaza & Garrow (1983) observed a similar increase in five lightly-clad, normal-weight women at 23° compared with 25–26°, although 24 h EE in five obsese women tended to be lower at the cooler temperature (Blaza & Garrow, 1983). Direct comparison of these results with the 5% increase observed in the present study is not possible because our temperature difference was greater, our subjects wore extra clothing at 20° and we included males and obese subjects in the study. However, the range of individual variation in response to the cooler temperature in the present study is within the ranges observed by Dauncey (1981) and Blaza & Garrow (1983).

Unlike Blaza & Garrow (1983) we did not observe a difference in mean response between our six normal-weight and our four obese subjects, although the range of individual response was larger in our obese subjects. Other studies have also observed variable effects of short-term exposure to mild cold in obese subjects which may be explained by different 'types' of obesity (Quaade, 1963, 1973; Lean & Murgatroyd, 1987).

The reason for the response to cold even in normally clothed subjects and for individual variations in response is not clear. None of our subjects reported shivering, although most said they felt cool at 20°. Feelings of coldness and physiological response to cold could be influenced by choice of clothing, but we could find no obvious relationship between clothing worn or blankets used and responses in our subjects.

Some of the individual variation in response may have been due to 'normal' intra-individual variation in 24 h EE. This averages 1–3% for measurements with standardized activities (Dallosso *et al.* 1982; Garby *et al.* 1984; De Boer *et al.* 1987) and 3–5% in subjects following sedentary but not standardized activity patterns (Warwick *et al.* 1988). Effects of familiarization with the calorimeter may also have contributed to individual variations in response, although most subjects spent an adaptive night in the chamber before their 24 h EE measurements, and an effect of treatment order was not found in a previous study (Warwick *et al.* 1988). Some of the individual variation in the present study may have been due to recorded (or unrecorded) differences in activity between the two measurements. For example, the negative response in subject no. 10, and the highest response in subject no. 4 may be partly explained by altered activity patterns which occurred even though all subjects had been asked to follow the same activity pattern and were required to keep activity records as a check.

However, as treatment order was randomized, the mean recorded activity level was the same at both temperatures, and the increase in EE was similar during the day and the night. The greater mean 24 h EE at 20° cannot be explained by treatment order or by obvious changes in level of activity. The possibility remains, however, that small differences in alertness, movement, or muscle tone occurred between the two measurements which would not have been noted on activity records.

Another explanation for the effect of mild cold on EE is through stimulation of metabolic processes independent of muscular contraction (Landsberg *et al.* 1984). These processes are influenced by the hormonal milieu and several studies have linked thermoregulatory capacity to the activity of the sympathetic nervous system or thyroid hormones, or both (Landsberg *et al.* 1984; Beard & Borel, 1988; Lean & Murgatroyd, 1988). We did not test our subjects for thyroid function or catecholamine excretion so we do not know whether variations in these factors influenced individual responses in the present study.

A number of other factors have been shown to influence metabolic response to severe cold. These include level of fatness (Daniels & Baker, 1961; Wyndham *et al.* 1968; Buskirk *et al.* 1963; Bittel, 1987), level of physical fitness (Bittel *et al.* 1988), acclimatization to cold

(Scholander *et al.* 1958) and level of food intake (Quaade, 1963, 1973; Brooke *et al.* 1973; Fellows *et al.* 1985). It is not known if these factors also influence the response to mild cold. However, in the present study there was no obvious relationship between response to mild cold and season studied, only two subjects (nos. 3 and 5) undertook any regular exercise and both of these showed intermediate responses, and body-weight was stable between measurements suggesting energy balance. All subjects had also been asked to standardize their dietary intake and activity on the day before the calorimetry measurements to minimize possible effects of previous diet or exercise.

In conclusion, the results of the present study suggest that mild cold increases EE in subjects wearing normal clothing and that temperature effects may need to be taken into account when estimating EE and energy requirements in humans.

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