Whole-body calorimetry studies in adult men

2. The interaction of exercise and over-feeding on the thermic effect of a meal

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1. Studies have claimed that an enhancement of the thermic effect of a meal (TEM) is an important adaptive mechanism to account for energy wastage during over-feeding.

2. Eight healthy normal-weight young men were studied during 1 week on a weight-maintenance diet and again during 1 week when they were over-fed by 50% with fat. During each experimental week, the subject occupied a whole-body indirect calorimeter at 26° for two separate periods of 36 h. The periods differed in the amount of exercise they contained. The thermic responses to the identical meals were measured during rest on one occasion and during exercise on a bicycle ergometer on the other.

3. On the maintenance diet the absolute TEM (kJ/min) was 1·51 (SD 0·42) at rest and 1·31 (SD 0·75) during exercise (no significant difference). The equivalent values (kJ/min) on the over-feeding diet were 2·2 (SD 0·48) and 1·97 (SD 0·64) (no significant difference).

4. The absence of a significant interaction between TEM and exercise was also demonstrated by the fact that the effect of over-feeding on total 24 h energy expenditure was unaffected by the subject's level of physical activity while in the calorimeter.

5. In conclusion, the present study has provided no evidence to support the hypothesis that TEM is enhanced during exercise.

It has been suggested that an interaction of exercise and diet-induced thermogenesis (DIT) may form an important component of the adaptive response to over-feeding. Miller *et al.* (1967) claimed that the thermic effect of a meal (TEM) during exercise is twice that during rest, but this finding was not confirmed by Swindells (1972). An enhancement of TEM during exercise has been demonstrated with a meal size greater than 4·2 MJ (Bray *et al.* 1974), after a day's over-feeding compared with a 24 h complete fast (Stock, 1980), and in normal weight but not obese women (Zahorska-Markiewicz, 1980). These three papers suggest then that exercise may enhance TEM but only when the body is already in positive energy imbalance. The previously-mentioned studies were all similar in that the energy costs of rest and exercise before and after a meal were compared. Other studies have taken a more indirect approach. For example, Bradfield *et al.* (1968) showed that TEM was greater when it followed exercise and Miller & Wise (1975) demonstrated that the energy cost of postprandial, but not preprandial exercise increased in line with the previous day's energy intake. This experiment was repeated, but the findings not confirmed, by Garby & Lammert (1977).

Despite the interest in this problem no mechanism has been postulated to account for a synergism between TEM and exercise. With the diversion of the blood supply to different working muscles that occurs with exercise, it might be logical to expect a delay or a reduction in TEM if this is dependent on metabolic activity in other organs. One possibility is that some humoral substance released during exercise, or the changes induced in the concentrations of various substrates in the blood, may increase TEM.

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The present study was designed to compare the TEM measured during rest and exercise. Since an enhancement could be an important way of adjusting the 24 h energy expenditure, the subjects were measured under conditions of weight maintenance and after a short period of over-feeding. Many of the experimental details of the study have already been described in the previous paper (Dallosso & James, 1984) which discussed the metabolic effects of over-feeding. The present paper limits itself to the question of whether TEM is enhanced during exercise.

METHODS

Subjects

Eight male volunteers were studied and the characteristics of the individual subjects are as given in the previous paper (Dallosso & James, 1984).

Experimental design

As already described (Dallosso & James, 1984) the study timetable consisted of two experimental periods of 7 d each (maintenance and over-feeding respectively). During the maintenance week the subject received a level of energy intake calculated to be sufficient to maintain body-weight and during the over-feeding week this energy intake was increased by 50% by the addition of fat to the diet which increased the fat contribution to energy intake from 30 to 50%. During both experimental weeks each subject occupied the calorimeter for two separate 36 h periods, designated high exercise (when TEM during exercise was measured) and low exercise (when TEM during rest was measured). The timetables of activity that the subject followed are given in Fig. 1. The subjects were always studied in pairs and the order of presentation of the different exercise programmes was alternated for subsequent pairs of subjects, as shown in Table 1 of the previous paper (Dallosso & James, 1984).

Measurement of TEM

TEM was always measured after the first meal of the day which was eaten promptly at 09.00 hours. This meal was 33% of the subject's 24 h energy intake and had the same composition as the diet as a whole. The maintenance diet was calculated to provide 13% of total energy from protein, 30% from fat and 57% from carbohydrate, while the over-feeding diet provided 9% of total energy from protein, 50% from fat and 41% from carbohydrate. Table 1 gives the energy contents of the test meals eaten by the subjects on both diets.

The indirect calorimeter used has been described in the previous paper (Dallosso & James, 1984). For the purpose of the present experiment it was essential to be able to look at the energy costs of periods of time as short as 30 min. This was not possible in earlier studies (Dallosso *et al.* 1982) because of the long response-time of the system. Since then a new method of analysis has been introduced (Brown *et al.* 1984) which has improved the response time. This was achieved by extending the previous analysis with terms taking account of the rate of change of gases stored within the calorimeter.

Calculation of TEM during rest and exercise

The timetables of activity that the subject followed while he occupied the calorimeter have been described in the previous paper (Dallosso & James, 1984) and are summarized in Fig. 1. The thermic effect of breakfast during exercise was calculated as the difference between the cost of cycling from 08.00 to 08.30 hours (preprandial) and the cost of cycling from 10.00 to 10.30 hours (postprandial); i.e. B minus A on the high-activity day. The thermic

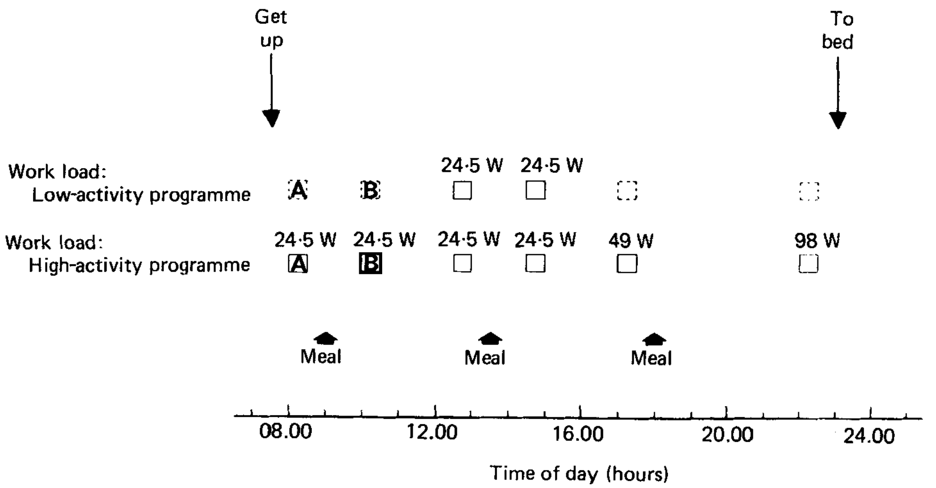

Fig. 1. Timetable of activities that each subject followed when he occupied the calorimeter. Meals were eaten at 09.00, 13.30 and 18.00 hours. On the high-activity programme there were six 30 min periods of cycling on a bicycle ergometer at three different work loads (□) and on the low-activity programme there were two 30 min periods of cycling (□) and four 30 min periods when the subject sat still on the bicycle (⬚). The thermic response to the first meal of the day was calculated as the absolute difference between periods A and B (for details, see pp. 66–67).

Table 1. *Calculated* metabolizable energy contents of test meals* (*kJ*)

Subject no.	Maintenance diet	Over-feeding diet
1	3335	5002
2	4346	6513
3	4683	7017
4	4009	6009
5	4346	6513
6	4346	6513
7	4683	7017
8	4346	6513

* Paul & Southgate (1978).

effect of breakfast during rest was calculated as the difference between the energy cost of rest (sitting still on the bicycle) from 08.00 to 08.30 hours (preprandial) and from 10.00 to 10.30 hours (postprandial); i.e. B minus A on the low-activity day. The absolute thermic responses (kJ/min) were compared.

Statistical methods

Analysis of variance was used to examine the TEM results, separating out terms for subjects (7 df) and treatments (1 df). The two treatment effects were the Enhancement effect (i.e. TEM during exercise *v*. TEM during rest) and the Regimen effect (i.e. TEM on the maintenance diet *v*. TEM on the over-feeding diet). A number of interactions between these effects and the order in which the subjects performed the different programmes of diet and exercise were also looked at (see Table 3). The treatment effects both had 1 df, and therefore

Table 2. *Energy cost (kJ/min) of preprandial and postprandial rest and exercise and the increase in metabolic rate as a result of feeding (thermic effect of a meal, i.e. TEM)*

Subject no.	Maintenance diet						Over-feeding diet					
	Rest			Exercise			Rest			Exercise		
	Preprandial	Postprandial	TEM	Preprandial	Postprandial	TEM	Preprandial	Postprandial	TEM	Preprandial	Postprandial	TEM
1	6·39	7·61	1·22	10·68	11·86	1·18	6·11	7·55	1·44	11·21	12·77	1·56
2	7·04	8·65	1·61	13·77	15·28	1·51	6·78	9·48	2·70	13·41	15·98	2·57
3	7·12	8·42	1·30	12·61	14·39	1·78	7·07	9·36	2·29	12·15	13·01	0·86
4	5·79	7·79	2·00	13·90	13·99	0·09	5·61	7·38	1·77	12·15	14·91	2·76
5	7·87	9·04	1·17	12·98	14·39	1·41	6·82	9·59	2·77	15·14	16·62	1·48
6	7·42	8·74	1·32	13·72	15·03	1·31	6·43	8·76	2·33	13·50	15·54	2·04
7	7·91	10·19	2·28	14·97	17·55	2·58	7·30	9·83	2·53	15·68	18·10	2·42
8	5·93	7·10	1·17	11·94	12·53	0·59	5·77	7·57	1·80	11·60	13·70	2·10
Mean	6·93	8·44	1·51	13·07	14·38	1·31	6·49	8·69	2·20	13·11	15·08	1·97
SD	0·82	0·96	0·42	1·33	1·74	0·75	0·61	1·03	0·48	1·63	1·85	0·64

Table 3. *Summary of analyses of variance on values for thermic effect of a meal*

Source of variation	t value
Regimen effect	3·25**
Enhancement effect	1·04
Regimen × subject interaction A	0·11
Regimen × subject interaction B	0·43
Regimen × enhancement interaction	0·07
Subject × enhancement interaction A	0·18
Subject × enhancement interaction B	0·14
Regimen × subject × enhancement interaction A	0·73
Regimen × subject × enhancement interaction B	0·93

Interaction A compares those subjects who did the high-activity programme first on the over-feeding diet with those who did the low-activity programme first on the over-feeding diet.

Interaction B compares those subjects who did the low-activity programme first on the maintenance diet with those who did the high-activity programme first on the maintenance diet.

** $P < 0.002$.

the F ratios, with 1 and 17 df, were expressed as t values, where the t value is the square root of the F ratio. The analysis was done using the GENSTAT statistical language. Means and standard deviations are presented.

RESULTS

Table 2 presents the individual energy costs of preprandial and postprandial rest and exercise and TEM on both the maintenance diet and the over-feeding diet. On the maintenance diet the mean TEM (kJ/min) was 1·51 (SD 0·42) at rest and 1·31 (SD 0·75) during exercise. On the over-feeding diet the mean TEM (kJ/min) was significantly higher during both rest (2·20 (SD 0·48)) and exercise (1·97 (SD 0·64)). Table 3 presents the results of the analysis of variance performed on the experimental values. The only significant effect was the increase in TEM on the over-feeding diet. The mean increase was 47% which compares well with the increase in meal size of 50%. There was no enhancement of TEM during exercise on either diet. The analysis of variance revealed no significant interactions between the variables and the order in which the experimental procedures were performed.

There are two ways of quantitating the TEM: to express the increase in metabolic rate as a percentage of the preprandial value, or to express the total increase in metabolic rate after the meal as a percentage of the energy content of the meal, a method which requires the metabolic rate to be measured until it returns to preprandial values. This second method is not possible here since the postprandial metabolic rate was only measured for 30 min. Miller *et al.* (1967) expressed the TEM as a percentage of the resting metabolic rate (RMR) and obtained values of 28% during rest and 56% during exercise. If this approach is adopted with the present results then, on the maintenance diet, the TEM at rest is found to be 22% of the basal metabolic rate (BMR) and 18% of the BMR during exercise. On the over-feeding diet, the TEM was higher during rest (34%) and during exercise (31%).

There were no significant correlations between the size of the meal and the TEM when the four experimental conditions were looked at separately. However, when all the values were combined there was a significant positive linear relationship between TEM and the size of the meal (r 0·57; $P < 0.01$).

DISCUSSION

The present work does not support the hypothesis that TEM is enhanced during exercise and that this is an important adaptive response to over-feeding. This is in agreement with the conclusion reached by Garrow (1978) that 'exercise potentiates thermogenesis either very little or not at all'. Given the conflicting evidence in the literature, a critical analysis of the various studies is warranted. The work most frequently quoted to support the enhancement hypothesis is that of Miller *et al.* (1967) and this has been criticized by Garrow (1974). In addition it is worth noting that, in the experiments of Miller *et al.* (1967), the meal sizes and compositions varied but are not given in the paper, and different methods of measuring oxygen consumption were used during rest and exercise. Another study is that of Swindells (1972), which also has drawbacks in its experimental design because, for example, the subjects were given a cup of coffee if the experiment continued beyond a certain time. Caffeine is now known to have an appreciable thermogenic effect (Acheson *et al.* 1980; Jung *et al.* 1981). The small enhancement found by Bray *et al.* (1974) is perhaps explained by Garrow (1978) who suggests that the enhancement observed may be a 'hobbling' effect caused by the discomfort of having eaten a large meal; in some instances a meal as large as 12·5 MJ was consumed. Stock (1980) found that TEM was increased during exercise after a day of substantial over-feeding, but not after a day of complete fast. However, in the Stock (1980) study, the order of presentation of the two dietary conditions was not reversed, with subjects fasting for a day before exercise the following morning, and then over-feeding throughout the day before tests were repeated the following morning. The enhanced effect observed on the second day of exercise seemed to be largely accounted for by the lower preprandial metabolic rate which occurred after the over-feeding day; the subjects seemed to be adapting to the experimental protocol.

Another frequently-quoted study is that of Miller & Wise (1975) who showed that the previous day's energy intake (4, 10 or 17 MJ) had no effect on the energy cost of preprandial exercise but was positively related to the energy cost of postprandial exercise. The exercise in the present study involved lifting a 3 kg weight with a pulley above the head using horizontal arm movements. In earlier work by this group (Wise, 1973), where the subjects performed the step test, no enhancement effect was detected. The type of exercise could conceivably be important since Åstrand *et al.* (1968), when comparing exercise which involved the arms being held above the head with cycling, found that, despite similar rates of oxygen consumption, this exercise produced marked differences in heart rate and blood pressure due to increased sympathetic vasoconstrictor tone. If an enhancement of TEM does depend on increased 'drive' in the sympathetic nervous system then this may explain why Garby & Lammert (1977) were unable to confirm the findings of Miller & Wise (1975) in a study where the exercise used was cycling.

The possibility needs to be considered that the design of the present study may have prevented any real enhancement in TEM being detected. The three variables that may be important in this context are type, size and timing of the meal being fed, the nature of the exercise itself and the type of subject being investigated. The present choice of postprandial measurement period was probably appropriate; the postprandial increase in O_2 consumption becomes apparent almost immediately after eating (Garrow & Hawes, 1972), is at its maximum value about 1 h after the meal (Strang & McClugage, 1931) and, depending on the composition of the meal, can continue for up to 6 h (Zed & James, 1982). Although there may be a critical meal size below which TEM is not enhanced during exercise, an increase in TEM was observed during over-feeding, indicating some spare thermogenic capacity. The final point relating to the meal is its composition. The present design, whereby over-feeding with fat alone was used, related to earlier findings where the response to fat feeding seemed to discriminate between lean and obese individuals (Zed & James, 1982). If sympathetic activation is the key to the interaction between over-feeding and exercise, then it could be argued that carbohydrate feeding may be an important factor, given the increasing evidence in man as well as in animals that carbohydrate feeding increases sympathetic activity (Minaker *et al.* 1982). If this is so on a short time-scale then the thermogenic response to the meal plus exercise during the maintenance period should have been more marked, since the meal chosen was of a high carbohydrate (albeit a low sucrose) content.

The studies which have compared TEM during rest and exercise have incorporated three different types of exercise: the step test (Miller *et al.* 1967; Stock, 1980), the bicycle ergometer (Bray *et al.* 1974; Zahorska-Markiewicz, 1980), and the treadmill (Swindells, 1972). The workload on the bicycle ergometer in the present study (24·5 W) was low compared with those used by Zahorska-Markiewicz (60 W) and Bray *et al.* (1974) (0–100 W) but appropriate in relation to the usual amount of exercise taken in everyday life. Whatever type of exercise is chosen it is difficult to obtain reproducible results. This is illustrated by the greater inter-individual variation in TEM during exercise compared with rest, despite training all the subjects, who cycled under supervision while using a metronome. These individual variations are taken into account by the analysis of variance.

The choice of lean subjects was designed to ensure that a thermogenic enhancement was found in view of Zahorska-Markiewicz's (1980) demonstration of an effect only in lean and not in obese subjects. No relationship between TEM and the percentage body fat was found in the present study so there was no suggestion that body fat was important.

DIT, a much broader term, is any increase in the rate of energy expenditure that can be attributed to diet, and necessarily includes the TEM. The present study allowed further analysis since the subjects occupied the calorimeter for 36 h on four different occasions which differed in the amount of exercise they performed and their level of energy intake. Therefore, if DIT is enhanced during exercise, it should be detected in the 24 h values; that is, there should be a greater response to over-feeding when the subjects were following the high-exercise timetable. This was not observed. The fivefold increase in work performed on the bicycle ergometer on the high-exercise day was associated with an increase in 24 h energy expenditure of 15% on the maintenance diet and 15·7% on the over-feeding diet. Analysis of variance (Table 6 of Dallosso & James, 1984) showed that there were no significant interactions between the level of exercise and the over-feeding for the 24 h values or for the daytime values (when the exercise took place).

In conclusion, the present study suggests that if an interaction between TEM and exercise does occur it only develops under very specific conditions. With the advent of whole-body calorimeters the energetic significance of any interaction can now be documented in a reproducible manner. The design of further studies requires considerable control of the preceding diet and the type of exercise, so that a clear effect can be demonstrated.

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