

SHORT COMMUNICATION

Effect of an acute fast on energy compensation and feeding behaviour in lean men and women[†]

AM Johnstone^{1*}, P Faber², ER Gibney³, M Elia⁴, G Horgan⁵, BE Golden⁶ and RJ Stubbs^{1‡}

¹Rowett Research Institute, Aberdeen, UK; ²Department of Anaesthetics, Aberdeen Royal Infirmary, Aberdeen, UK; ³Department of Biological and Nutritional Sciences, Faculty of Agriculture and Biological Sciences, University of Newcastle, Newcastle, UK; ⁴Institute of Human Nutrition, Level C (113), West Wing, Southampton General Hospital, Southampton, UK; ⁵Biomathematics and Statistics Scotland, Rowett Research Institute, Aberdeen, UK; and ⁶Department of Child Health, University of Aberdeen, Medical School, Foresterhill, Aberdeen, UK

AIM: Humans appear to defend against energy deficit to a greater extent than energy surplus. Severe dietary energy restriction resulting in 5–30% weight loss often leads to hyperphagia and weight regain in lean subjects. However, the period of time over which fasting is often endured in Western society are far shorter, ~1–2 days. This study examined how a 36 h fast effected the subsequent day's energy and nutrient intake in a group of 24 healthy, lean men and women.

METHOD: Subjects underwent two 2 day treatments, termed 'fast' and 'maintenance'. During the 'fast' treatment, subjects were fed a maintenance diet on the day prior to the fast (day –1) to prevent overeating. They then consumed non-energy drinks only, from 20:00 h on day –1 to 08:00 h on day 2 (*ad libitum* feeding day), thus fasting for 36 h. On the 'maintenance' protocol, subjects received a maintenance diet throughout day 1. Throughout day 2 they had *ad libitum* access to a range of familiar foods, which were the same for both treatments. Body weight, blood glucose and respiratory quotient were used as compliance checks. Hunger was monitored on day's –1, 1 and 2 for the fast treatment only.

RESULTS: On day 2, average energy intake was 10.2 vs 12.2 MJ/day (s.e.d. 1.0) on the post-maintenance and post-fast periods, respectively ($P=0.049$). Subjects altered feeding behaviour, in response to the fast, only at breakfast time, selecting a higher-fat meal ($P<0.005$). Compared to day –1, motivation to eat was elevated during the fast ($P<0.05$). This continued until breakfast was consumed during the re-feeding period (day 2), when values then returned to baseline.

CONCLUSION: These data suggest that a 36 h fast, which generated a negative energy balance of ~12 MJ, did not induce a powerful, unconditioned stimulus to compensate on the subsequent day.

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Introduction

It has been stated that human behaviour has evolved to defend against energy deficit to a greater extent than energy surplus.¹ Studies of chronic undernutrition in lean subjects who have lost 15–30% body weight as a result of semi-starvation show people may eat as much as 25–42 MJ/day

when subsequently allowed to feed *ad libitum*.^{2,3} Other shorter-term studies of severe dietary energy restriction, in lean subjects (resulting in 5–10% weight loss), have also reported hyperphagia and weight regain upon restitution of *ad libitum* feeding.⁴ However, there is a paucity of data on the effect of shorter periods of severe energy restriction that are associated with 0–5% loss of body weight. In Western society, most adult humans fast intermittently for only 1–2 days⁵ as a means to control body weight. Ironically, there is little or no information on feeding responses to an acute energy deficit. Therefore, the aim of this study was to examine the extent to which healthy male and female subjects undergoing a short-term total fast (36 h), compensate by altering their energy intake and macronutrient selection. It was hypothesized that on the day following this short period of starvation, subjects would show a marked tendency to compensate.

*Correspondence: A Johnstone, Rowett Research Institute, Greenburn Road, Bucksburn, Aberdeen AB21 9SB, UK.
E-mail: amj@rowett.ac.uk

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[‡]Member of the Aberdeen Centre for Energy Regulation and Obesity (ACERO).

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Methods

Subject recruitment and physical characteristics

Twelve lean men (mean (s.d.) age 27.4 (9.7) y; height 1.77 (0.10) m; weight 70.5 (7.9) kg; body mass index (BMI, kg/m²) 22.4 (2.1)), and 12 lean women (mean (s.d.) age 20.6 (2.9) y; height 1.64 (0.65) m; weight 60.9 (6.5) kg; BMI (kg/m²) 22.6 (2.2)), were recruited by advertisement. Inclusion criteria specified that subjects were normal-weight (BMI 20–25), not consuming any specialized diet and not taking any medication (except oral contraceptives in women). During recruitment, subjects underwent a medical examination. Their general practitioners were also contacted to confirm medical suitability to participate in the study. All subjects were interviewed and informed of the procedures involved before signing a consent form. Subjects were unaware that the main outcome variable was feeding behaviour, although it was not difficult for them to deduce this was being monitored. Upon recruitment, all subjects completed a Dutch Eating Behaviour Questionnaire (DEBQ)⁶ to assess degree of emotionality, externality and restraint on eating behaviour. Ethical approval was given by the Joint Ethical Committee of Grampian Health Board and the University of Aberdeen.

Measurement of baseline anthropometry and resting metabolic rate

Height was measured to the nearest 0.5 cm using a stadiometer (Holtain Ltd, Crymych, Dyfed, Wales). Subjects were weighed each morning of the study by a study investigator, after voiding and before eating, wearing the same bathgown, to the nearest 50 g on a digital scale (DIGI DS-410, CMS Weighing Equipment, London, UK). Resting metabolic rate (RMR) was measured first thing in the morning, by indirect calorimetry

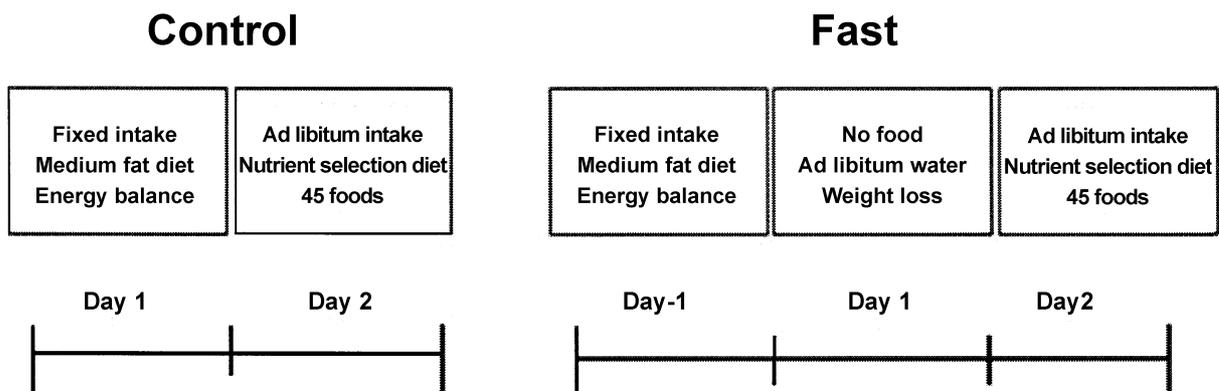
over 30–40 min using a ventilated hood system (Deltatrac II, MBM-200, Datex Instrumentarium Corporation, Finland) on subjects who had fasted overnight. Subjects were required to refrain from any physical activity prior to measurement. During the measurement, subjects lay on a bed in a thermoneutral room instructed to lie still but not to fall asleep. RMR was calculated using the equations of Elia and Livesey.⁷

Study protocol and techniques

Each subject acted as their own control. They completed a 2-day control period (maintenance) and a separate 2 day test period (fast; see Figure 1 for the protocol outline). The order of treatments was randomized across subjects. On the 'fasting' (fast) treatment (day –1), food was also provided as a maintenance diet, at 1.6× resting metabolic rate (RMR) to avoid pre-fasting variability in food intake. Subjects then fasted from 20:00 h on day –1 until 08:00 h on day 2. When fasting, subjects only consumed water or non-energy-containing beverages. Thus, they received no energy from 20:00 h on day –1 until 08:00 h on day 2 (the outcome day; 36 h). During the 'maintenance' treatment, subjects were fed to 1.6× RMR throughout day 1. During day 2 on both treatments, subjects were given *ad libitum* access to a balanced selection of 15 high-protein (HP), 15 high-carbohydrate (HC) and 15 high-fat (HF) supermarket-type foods. This diet has been specifically designed to quantify changes in food, energy and nutrient intake.⁸

Body weight (BW) was measured each morning after voiding and prior to eating. Motivation to eat was assessed hourly during waking hours using visual analogue scales (VAS; as detailed in Johnstone *et al*⁹) throughout the fasting manipulation only (days –1, 1 and 2).

Protocol



12 lean men and 12 lean women were each studied twice in a randomised order

Figure 1 Protocol diagram.

Formulation and preparation of the diets

The composition of each meal in terms of energy, fat, carbohydrate, protein and non-starch polysaccharide was calculated from McCance and Widdowson's *The composition of foods*, 5th edn and supplements.¹⁰ The food was prepared daily by the dietetic research assistant in the metabolic kitchen. The maintenance diets were formulated to contain, as far as possible, normal everyday ingredients and to contain recognizable food which varied little in composition (for example pre-prepared foods were not used).

Presentation of the diets and measurement of food intake

On maintenance days, diets were packed into a large cool bag for subjects to take away with them. During the *ad libitum* days, subjects had continuous access to foods throughout the day and could come to the HNU to consume these foods as and when they required. Subjects attended the HNU from 07:30 until after lunchtime. From 14:00 onwards, all subjects could also take food items to other parts of the campus in a large food bag (size of a picnic hamper) in which were placed the HF, HC or HP foods to which they had *ad libitum* access. If subjects consumed all or part of one food, more items of that food were provided. All subjects were working or living locally and were able to come to the unit or phone to request any additional foods they required. It was thus ensured that subjects had access to these foods throughout the day and a member of staff was continually on call to deal with any requests or problems in relation to the protocol. Prior to leaving the campus, subjects met the duty member of staff who replenished the selection of foods in the food bag, which they could then take home. All volunteers returned remaining food items, leftover packaging and food remains to the HNU the following morning. All foods were weighed before and after ingestion. The investigator noted, to the nearest gram, the weight of the food. During the fast, subjects had *ad libitum* supply to water and de-caffeinated drinks, only. Energy and nutrient intakes were calculated using the Diet 5 programme (The Robert Gordon University, Aberdeen), which is based on current UK food tables.¹⁰

Statistical analysis

The visual analogue scales (VAS) were analysed using analysis of variance (ANOVA) by calculating a mean rating for each 24 h period with diet, gender and time treatment factors and subject as a blocking factor. Temporal analysis was conducted by splitting the day into hourly time points calculating a mean rating for each interval. VAS were recorded only within the fasting treatment.

Mean daily 24 h food, energy and macronutrient intakes during the *ad libitum* periods were analysed by ANOVA, with diet (condition), gender and time as treatment factors and subject as a blocking factor. The day was split into four periods corresponding to breakfast (08:00–10:00), lunch (12:00–14:00) and dinner (17:00–19:00) and snack

(inter-meal interval) intake to observe changes in feeding patterns. End-of-day questionnaires were analysed by ANOVA with diet and gender as treatment factors and subject as a blocking factor.

Body weight change was analysed by a one-sample *t*-test to establish whether weight loss was significantly different from zero. Difference between treatment and control period was assessed by ANOVA. All analyses were performed using the Genstat 5 statistical program (Genstat 5, Rothamstead Experimental Station, Harpenden, UK).

Results

Compliance to starvation

Compliance to the fast was checked in three ways: (i) fasted blood glucose was measured by a finger prick, using capillary whole blood (Accutrend, Boeringer, USA). Mean values were 4.0 (s.d. 0.3) and 3.2 (s.d. 0.6) mmol/l after an overnight fast and 36 h fast, respectively. These values are similar to those recorded from a much larger subject group;¹¹ (ii) respiratory quotient (RQ) was measured using a metabolic cart (Sensor Medics, The Netherlands), after an overnight fast and 36 h fast, before consumption of food. On average, RQ decreased significantly ($P < 0.05$) from 0.81 (s.d. 0.04) to 0.73 (s.d. 0.05). This is similar to values observed in fasted subjects in studies of a similar duration.^{12,13} (iii) Weight loss was also used as an index of compliance to the fast, when considered in relation to (i) and (ii) above.

Restraint, emotionality and externality

Results of the DEBQ are scored from 1 to 5 for factors restraint, emotionality and externality. The average values achieved for emotionality, externality and restraint were 1.89 (s.d. 0.83), 3.03 (s.d. 0.41) and 2.24 (s.d. 0.94), respectively, for the men and 2.15 (s.d. 0.63), 2.98 (s.d. 0.67) and 3.17 (s.d. 0.89) for the women. The subjects can be classified as being mildly restrained in their eating behaviour.

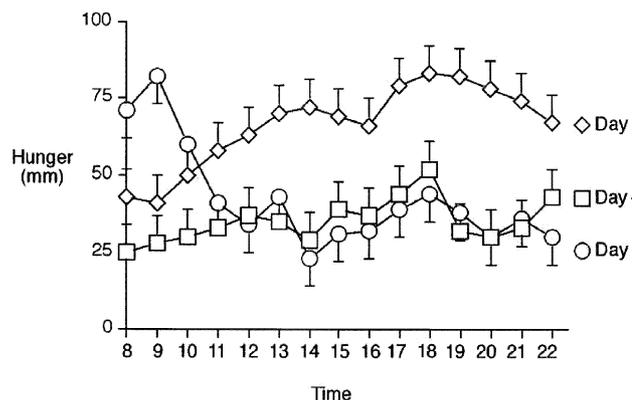


Figure 2 Average (s.d.) hourly hunger for the fasting protocol, days – 1 (maintenance), 1 (fast) and 2 (*ad libitum* intake) for the men and women combined ($P < 0.001$).

Table 1 Average food, energy and nutrient *ad libitum* intake on the control and fast treatments, for the men and women combined

Treatment	Food (kg)	Energy (MJ)	Protein (MJ)	Fat (MJ)	Carbohydrate (MJ)
Control	1.85	10.2	1.9	3.7	4.6
Fast	2.29	12.2	2.2	5.1	4.9
s.e.d.	0.18	0.97	0.17	0.33	0.59
P	0.027	0.049	0.065	< 0.01	0.584

Body weight change

All subjects lost weight during the 36 h fast (day 2 minus day -1). There was no significant difference between the men and women ($P=0.082$), with an average loss of 1.33 kg (s.d. 0.55) in the men and 1.00 kg (s.d. 0.30) in the women. There was slight evidence that men tended to lose more weight than women, on account of their larger size. This weight change corresponds to around 1.5% original body weight. Weight change was significantly different from zero ($P < 0.001$) and higher than weight change during the control period (day 2 minus 1; $P < 0.001$), which was -0.02 kg (s.d. 0.73) for the men and -0.25 kg (s.d. 0.47) for the women.

Hourly assessment of motivation to eat using VAS

On average, subjective hunger was affected by nutritional status with mean ratings of 35, 66, 42 mm (s.e.d. 3.0; $P < 0.001$) on day -1, 1 and 2, respectively, for all subjects. Even though subjects were not eating on day 1 (fasting day), they exhibited a typical rise in hunger at mealtimes, as indicated by a significant time interaction ($P < 0.001$). Figure 2 shows hourly hunger for all subjects on days -1 (maintenance), 1 (fasting) and 2 (*ad libitum* feeding). Although the 24 h mean values for motivation to eat had not returned to baseline by day 2, with subjects reporting still feeling more hungry ($P < 0.05$) and with a higher prospective consumption on day 2 (*ad libitum* feeding) compared with day -1 (maintenance), a closer inspection of the hourly data revealed that this effect was due to the higher pre-breakfast values. When these morning values were accounted for, there was no significant difference between days 2 and -1. Reported fullness had returned to baseline on day 2 compared with day -1. Sensations of fullness and prospective consumption showed a similar trend to hunger, with subjects feeling less full on day 1 compared with day -1 or 2, for all subjects combined ($P < 0.001$). Volunteers did not report any significant change in subjective thirst, energy, fatigue, tiredness, tenseness or contentment during the fast. Some of the subjects did not record fluid intake while on the fast, however people do tend to increase fluid intake when fasting.^{4,15} Both genders reported similar change in ratings, with no significant gender-day interaction.

Ad libitum food, energy and nutrient intake

Subjects showed a significant elevation of mean daily energy intake (EI) after a 36 h fast (Table 1). This however, was far

from sufficient to restore energy balance. On average, subjects consumed 10.2 vs 12.2 MJ/day (s.e.d. 1.0) during the post-maintenance and post-fast periods, respectively ($P=0.049$). This compares to an energy intake on maintenance days (calculated at $1.6 \times$ measured RMR) of 10.0 MJ (s.d. 1.00) (8.5 and 11.4 MJ/day for the women and men, respectively). The increased EI was linked to a greater consumption of food ($P=0.027$), with average intakes of 1.8 and 2.3 kg/day (s.e.d. 0.2) during the post-maintenance and post-fast periods, respectively. The main effect on EI was consumption of additional fat of 3.7 vs 5.1 MJ/day (s.e.d. 0.3; $P < 0.001$), respectively. Post-fast carbohydrate and protein intakes were not significantly elevated due to the fast.

Food, energy and nutrient intakes were analysed additionally by division into mealtimes (breakfast, lunch, dinner) and snack intake for each group. There was no significant difference between the amount or energy content of foods consumed at the different mealtimes or snacks during day 2, although, subjects tended to consume slightly more at breakfast and lunch on the post-fast treatment in comparison with the control period. Notably, fat intake was almost double at breakfast after the fast than during the control period, with average intakes of 0.9 vs 1.5 MJ, respectively ($P < 0.05$). In addition, the women increased the weight of snacks eaten ($P=0.038$), from 0.5 to 0.8 kg (s.e.d. 0.1). This also significantly increased snack energy, protein and fat intake for women.

Discussion

Effect of a short-term fast on appetite and motivation to eat

Subjects consumed much less energy than required to compensate for the energy deficit induced by the fast. Average energy intake only increased 20% above control values on the post-fast *ad libitum* day. On the control treatment, the *ad libitum* intakes were on average, $1.6 \times$ RMR, approximately the level required to maintain energy balance for a group with these characteristics, under sedentary conditions.¹⁴ Three men and three women (25%) did not increase energy intakes in response to the fast and, when their intakes are excluded from the analysis, average intakes were 156% of control, or 3-4 MJ extra energy, which amounts to approximately 25-30% compensation for the 12 MJ energy deficit induced by the fast. This lack of compensation in general appears to have been a real effect since compliance to the fast was good. Both the anthropometric and biochemical

measurements provided no evidence that compliance was poor, since the results are consistent with those obtained in other well-documented starvation studies.^{12,13}

There was, however, a pronounced change in feeding behaviour for the first meal after the fast. Subjects preferentially selected a higher-fat intake, perhaps as a mechanism to increase energy intake by choosing the most energy-dense foods. This preferential selection of a high-fat intake at breakfast was not apparent throughout eating episodes during the remainder of the day. Therefore, the effects of the breakfast intake on satiety appear to have swamped any systematic urge to eat, as a consequence of the fast. Interestingly, both men and women appear similar in this respect. As far as we are aware, this is the first study to formally examine the effect of an acute 36 h fast on *ad libitum* energy and nutrient intake. Previous studies in lean men have all been conducted under conditions of either semi-starvation or total starvation.²⁻⁴ These studies differ from the present in that a much larger weight loss (5–30% original body weight) was induced by a longer period of energy restriction. Under these conditions, there is a much stronger drive to overeat and re-gain body weight. In each study, subjects tended to rapidly re-gain the lost weight (and indeed overshoot), due to increased *ad libitum* intake. We argue here that the 'percentage regulatory error' in energy stores was very small as a consequence of a 36 h fast, once water loss is taken into account. This would amount to ~0.5 kg tissue and 0.5 kg of fluid loss in a 65 kg adult, or ~0.08% change in energy stores. Nonetheless, the energy deficit did not go undetected and if followed up for longer it is possible that subjects would have compensated more. The energy deficit was detected by elevated hunger during the fast. However, the changes in both detection of the energy deficit and in feeding behaviour were largely restricted to the first meal after the fast. Thus the apparent higher levels of hunger on day 2 were largely due to elevated pre-breakfast ratings. While hunger has been measured over longer periods of fasting in lean subjects^{4,16} and obese subjects,^{17,18} these are situations that do not really compare to the present acute study.

While a number of studies have examined the effects of an acute energy surfeit on subsequent EI, there are fewer reports on the effect of an acute energy deficit on subsequent feeding behaviour. In many short-term studies, day-to-day compensation is extremely weak.¹⁹⁻²¹ While energy compensation can be quite precise for energy deficits within a day,^{22,23} subjects do not compensate well the day after for mild to moderate energy deficit. One other study has found similar degree of compensation, to the present study, but on a day-to-day basis.²⁴ Indeed, even in the longer term, over periods of 7 days, we have found subjects only tend to compensate by ~0.2–0.4 MJ/day for energy deficits induced by either diet or by exercise (unpublished data).

The absence of an acute, accurate compensatory response to the short-term energy deficit caused by the 36 h fast does not indicate tight physiological or metabolic control over day-to-day energy balance. These issues have far more than theoretical relevance because adult humans can undergo

acute alterations in EB on a day-to-day basis, which may accumulate to influence body weight if accurate compensation does not occur over the longer term. Clearly, the fast induced a physiological and psychological change in the subjects, which was reflected by alteration in motivation to eat and feeding behaviour. Furthermore, this study was conducted in mildly restrained, lean individuals and it may be that obese or more restrained individuals may respond differently to a short-term fast.

It should be noted that there are considerable limitations to this pilot study. It used a small number of non-randomly selected, mildly restrained, lean, young, men and women. Motivation to eat was only measured on the fasting treatment, the duration of the fast was very short, as was the *ad libitum* feeding period. The data may not be generalizable to other subject groups such as children, older adults, the obese or highly restrained subjects.

General conclusions

In conclusion, these data suggest that subjects cannot, or are not inclined to consume enough food to restore 24 h energy requirements subsequent to an acute 36 h total fast. In response to the energy deficit, subjects altered feeding behaviour only at breakfast time, selecting a high-fat meal. Thereafter, feeding behaviour and motivation to eat were unaffected, which suggests that post-absorptive feedback over this time period is very weak.

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