



One day of food restriction does not result in an increase in subsequent daily food intake in humans ☆,☆☆

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ABSTRACT

The purpose of this study was to examine the effect of one day of food restriction on subsequent spontaneous daily food intake and the recovery of body weight in humans. Twenty-two, non-restrained females were fed from Monday to Friday for four weeks using food prepared and measured in the Cornell Metabolic Laboratory. For the first week, all participants ate ad libitum. For each subsequent Monday, participants were divided into three groups in which either they (a) ate ad libitum, (b) were restricted to eating 1200 kcal (5040 kJ), or (c) were fasted. From Tuesday until Friday participants ate ad libitum. During each session, all food consumed as well as body weight were measured.

Body weight did not change following the day of ad libitum eating, but decreased significantly after the day of food restriction decreasing still further after fasting, indicating high compliance with study protocol. Although the loss in body weight was regained within four days, the recovery was accomplished without any increase in spontaneous food intake. Although no direct measurement of energy expenditure was made in this study, the results strongly suggest that decreases in metabolic rate play a more dominant role in the recovery of body weight following food restriction than the control of food intake.

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The idea that food deprivation necessarily leads to increased hunger and subsequent food intake is both intuitive and accepted in the fields of psychology and physiology. Indeed, overeating in response to food restriction is given as the major reason people fail to maintain a reduced energy intake and weight loss after a diet regimen [2,3].

Despite the intuitive appeal of this idea, the evidence from the literature is quite sparse and inconsistent. Telch and Agras [4] measured ad libitum food intake at a buffet served either one hour after eating lunch or skipping lunch (6 h deprivation). The food deprivation resulted in a significantly greater food intake. However, it is not clear from the experimental design whether the authors were observing an effect of food deprivation or of food “preloading”. It is well known that feeding people within one to two hours prior to eating (preloading) significantly suppresses subsequent food intake [5].

In a similarly designed study, the same authors compared the spontaneous food intake at a buffet meal served either two hours after

either eating lunch or skipping both breakfast and lunch (14 h deprivation) [6]. Their results were considerably less clear than those from their first study. Although the authors report that deprivation significantly increased food intake, close examination of the data reveals the presence of an interaction between two “mood” conditions that were experimentally imposed by the authors. The difference in food intake between the high deprivation condition (14 h) and the low deprivation (2 h) resulted in a mean difference in intake of about 1100 kcals (4.6 MJ). However, imposing a “negative” mood on the participants resulted in no difference in intake between the two deprivation conditions (8 ± 33.6 KJ).

Hetherington et al. [7] also used food deprivation to study differences in people with eating disorders. A 19-hour food deprivation was imposed beginning 10:00 pm the previous night and continuing until 5:00 pm the next evening. The amount of food eaten at the subsequent meal was measured. The control groups without eating disorders showed a small, non-significant increase in food intake in response to the food deprivation. Only one of the three eating disordered patients showed a significant increase in food intake following the food deprivation. Similarly, Johnstone et al. [8] found that participants who underwent a 36-hour fast increased energy intake by only 20% on the day following the fast.

Because of the paucity of experimental information on this fundamental question regarding the effect of food deprivation on the spontaneous intake in humans, the following study was performed. The within-subject study measured all food consumed from Monday to Friday for three consecutive weeks. On Monday of each week the

☆ Some of these data were presented at a Symposium held at Columbia University and published [1].

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participants ate either (a) ad libitum, (b) were restricted to 1200 kcal (5040 kJ), or (c) fasted.

1. Methods

1.1. Participants

The participants were 22 non-smoking females, with ages ranging from 19–46 years (26.9 ± 7.3), and weighing 53.7–88.0 kg (67.0 ± 9.7 kg), all having a BMI less than 25. All potential participants were initially screened by telephone, and those who met the study criteria were invited for an interview. A dietary restraint scale [9] was completed by each participant in order to eliminate women who were overly concerned with their body weight and food intake. Only participants with a score of less than 15 were accepted into the study. A four-day diet record was completed by each interviewee in order to eliminate participants with unusual meal patterns (e.g. erratic or monotonous meals).

Prospective participants who met these preliminary criteria were invited to a group meeting. The study was described to the participants as an investigation of the effects that fasting and semi-fasting have on energy expenditure. They were told that the outcomes of interest involved certain urinary metabolites that may be altered by the fast. All participants were screened by a physician in order to confirm that participants were all in good health and were not taking regular medication. Signed informed consent forms were obtained. The protocol was approved by the Cornell University Committee on Human Subjects.

Twenty-four women were originally chosen to participate. However, two participants dropped out during the first week of the study and were excluded from all analyses. Participants were not given any compensation besides the food served as part of the study.

1.2. Diet

All foods were prepared by the Cornell University Metabolic Unit. A five-day rotating mixed diet was available ad libitum. The caloric content of each food item was determined by an adiabatic bomb calorimeter after homogenization and freeze-drying of sample aliquots. All food items, except orange juice, contained between 35–40% of energy as fat. Thus, dietary fat composition was constant across any chosen quantity and combination of food items. Each of the five menus was served on the same day of the week throughout the study. A multi-vitamin and mineral supplement was also given each day at breakfast to ensure nutritional adequacy of the diet.

Breakfast and dinner were served in the Metabolic Unit, while lunch and snack items were selected at breakfast and taken out. Food items for each meal were presented on a buffet table. The participants were allowed to take as much or as little of any food item and were told that they did not have to eat everything that was taken from the buffet table. The foods were weighed in individual plates or bowls to the nearest 0.1 g on an electronic balance, by the staff. The containers, and any residual food, were reweighed and recorded on daily food record sheets after each meal. The time of lunch and snacks consumed outside the unit was recorded by the participants on the food wrappers and returned along with any uneaten food portions at the next meal.

Weekends were used as “wash-out” periods between treatments in order to eliminate any possible carry-over effects between treatments. Participants kept food records during the weekends since their food was not provided by the laboratory. Participants were instructed to eat the same kinds of foods that they ate during the first weekend of the study for the subsequent two weekends.

Non-caloric beverages were available ad libitum throughout the study, and one alcoholic beverage was permitted on the weekends. Participants were limited to three caffeinated beverages per day. The

desired amount of caffeinated beverages was chosen by each subject at the beginning of the study, and maintained constant throughout the study. The total number of beverages consumed outside the unit was recorded each morning for the previous day.

1.3. Body weight

Overnight fasted body weight was measured every weekday morning for each subject using a digital scale calibrated to 100 g (Health-o-meter, Continental Scale Corporation, Bridgewater, IL). To ensure accuracy participants were weighed in their undergarments after voiding. Subjects were not told their weights and were asked to refrain from weighing themselves during the study.

1.4. Procedure

Food intake was measured for the four five-day periods from Monday to Friday. During the first week, all participants were instructed to eat as much or as little as they desired. On Monday of the second week, the participants were randomly assigned to one of three groups. As depicted in Table 1, each group received one of the following treatments on each of the three succeeding Mondays: (a) Ad Libitum Treatment where participants could eat as much as they wanted at each meal, (b) Restricted Treatment where participants received a total of 1200 calories for the entire day, and (c) Fasting Treatment where participants received no food the whole day. All participants were allowed to consume as many non-caloric beverages as they wanted.

Each morning, participants completed a questionnaire assessing illness, menses, activity, and any dietary deviations on the previous day. Participants were asked to maintain their normal activity levels throughout the study. If participants consumed any food not prepared by the metabolic unit was consumed, the energy value of the food consumed was added to the total energy intake using a computerized food database to estimate energy content. At the end of the study, the participants were debriefed with the full details of the study. Participants were requested to reveal any dietary deviations not previously reported, but no reports were made.

1.5. Statistical analysis

The data were analyzed using the Statistical Analysis System. (Version 8) Differences between treatments were tested using analyses of variance (GLM) and multiple regression analyses. The effects of individual subject, week of study and caloric treatment were included in each model.

1.6. Results

Because the order of testing produced no significant difference in either food intake or body weight, the data from the three groups were combined for the statistical analysis.

Mean body weight during the course of the week is illustrated in Fig. 1. Mean body weight on Tuesday following a day of food restriction was statistically lower than following a day of ad libitum consumption on Monday ($p < 0.05$), but was not statistically different by Wednesday. Mean body weight following a fast on Monday

Table 1
Experimental paradigm.

	Group 1	Group 2	Group 3
Week 1	Ad libitum	Ad libitum	Ad libitum
Week 2	Ad libitum	Restricted	Fasting
Week 3	Restricted	Fasting	Ad libitum
Week 4	Fasting	Ad libitum	Restricted

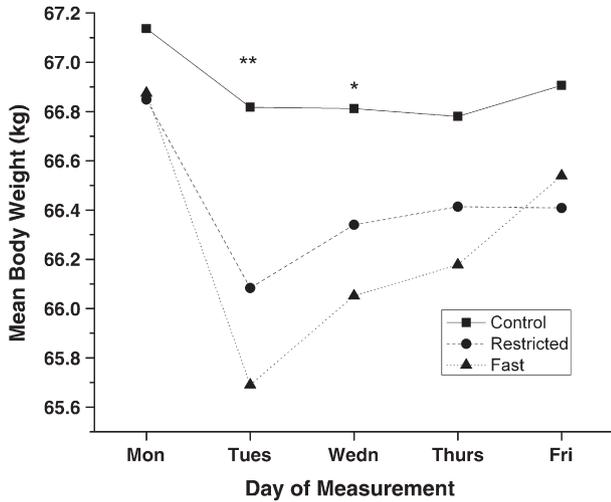


Fig. 1. Mean body weight throughout the five measurement days for each condition. ** Weight loss after fasting $p=0.001$, weight loss after restricted feeding $p=0.05$ * weight loss after fasting $p=0.05$.

remained statistically lower than after the eating ad libitum on Monday until Thursday ($p<0.01$).

The mean change in body weight on Tuesday in response to the Monday dietary treatment is shown on the left panel of Fig. 2. Following a day of ad libitum consumption, participants lost a small, but statistically insignificant amount of body weight. However, after a day of energy restriction (1200 kcal (5040 kJ)) there was a significant loss in body weight (0.76 ± 0.15 kg, $p<0.05$). Fasting on Monday caused an even greater weight loss (1.18 ± 0.12 kg, $p<0.001$).

The right panel in Fig. 2 shows the recovery of body weight from Tuesday to Friday. Weight did not change following a day of eating ad libitum, but a significant gain in body weight was apparent after being food restricted (0.33 ± 0.05 kg, $p<0.01$) and a greater gain occurred following the fast (0.85 ± 0.08 kg, $p<0.001$).

The measurement of daily food intakes for the individual participants was remarkably consistent. The mean amount of energy consumed during the baseline (9400 ± 112 kcal per week; 39.5 ± 0.47 MJ per week) was not statistically different from that of the first week for the ad libitum condition group (9929 ± 229 kcal per week; 41.7 ± 0.96 MJ per week). The consistency of the intake measurements was corroborated by the high test–retest correlation between the

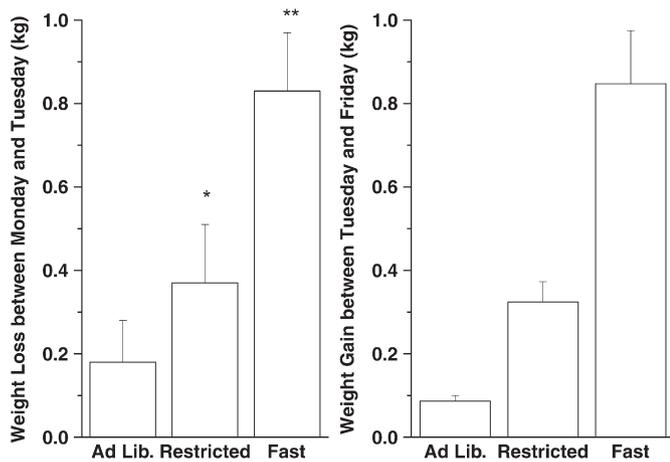


Fig. 2. Left panel shows the mean and standard error of the weight loss from Monday morning until Tuesday morning after eating ad libitum, restricted feeding, and total fasting on Monday. Right panel depicts the mean and standard error of the weight gain from Tuesday morning until Friday morning after the three conditions. * Different from ad lib; $p<0.05$; ** different from ad lib; $p<0.01$.

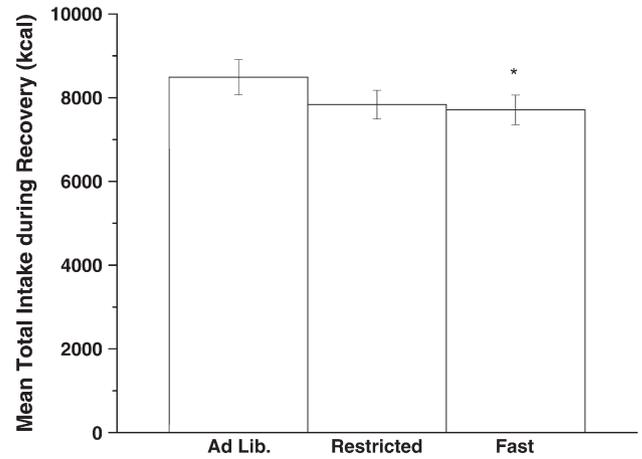


Fig. 3. Mean and standard error of total daily intake on the four days following the dietary treatments. * Different from ad lib; $p<0.05$.

energy intake of the individual participants measured during the two periods ($r=0.80$; $p<0.0001$).

The total energy consumed on the four days of recovery following the intervention is shown in Fig. 3. Intake did not increase after either the energy restriction or the day of fasting. In fact, energy intake following the day of fasting was significantly lower ($p<0.05$) than after a day of ad libitum feeding.

A closer examination of the energy intake data across the week is shown in Fig. 4. This figure is a cumulative curve of mean intakes for each of the three treatments across the five days of observation. Several aspects of this figure should be noted. First, mean daily energy intake was significantly affected by the manipulation, not only on the first day when intake was experimentally manipulated, but also on every succeeding day. Second, cumulative intake is highly linear, producing a regression coefficient of more than 0.99 for all three conditions. Finally, the slopes of the three regression lines were not significantly different from each other. This indicates that neither the day of energy restriction nor the day of fasting resulted in any change of spontaneous food intake throughout the four days of recovery from the cumulative intake function following ad libitum consumption.

Fig. 5 depicts the sensitivity and reliability of the measurement of food intake by showing the correlations in food intake between total energy consumed on the day following eating ad libitum and either

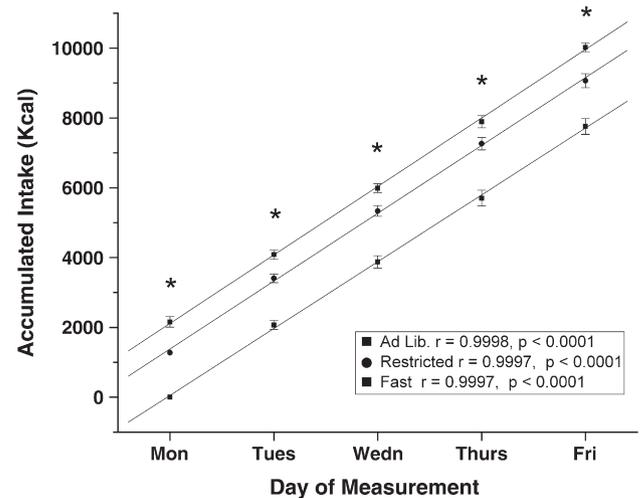


Fig. 4. Cumulative mean intake across the five measurement days. Slopes of the three functions were not different from each other. * Both conditions different from ad libitum $p<0.001$.

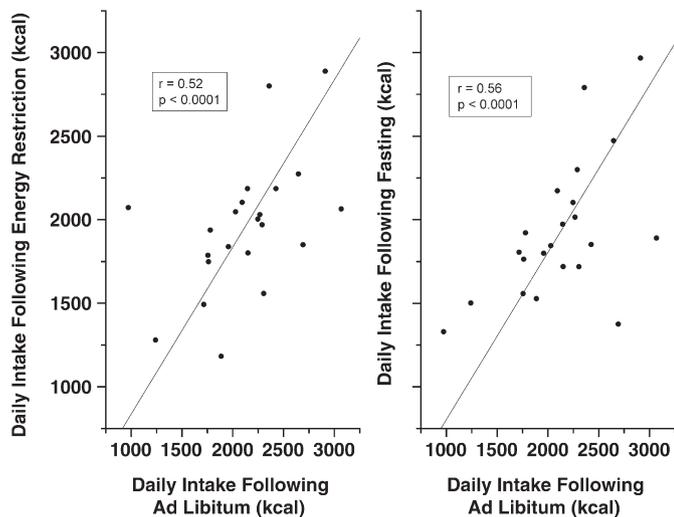


Fig. 5. Left panel is a scatterplot of the individual participants' energy intake on the day following the ad libitum treatment and after the restricted feeding. The line represents the regression equation with the slope set at 1.0. Right panel is a similar plot of the same participants on the day following the ad libitum treatment and after a day of fasting.

the day after restricted feeding or the day after the total fast. The correlation coefficients were 0.52 and 0.56, respectively, and were both statistically significant ($p < 0.001$).

2. Discussion

The results from the present study demonstrate women do not compensate for one day of partial or total fast by increasing their food intake over the subsequent four days of measurement. Although counterintuitive, these findings are consistent with the few studies that have examined the question. Johnstone [8] found non-eating disordered participants increased their intake by only 20% following a day of fasting, a finding substantiated by Hetherington [7]. In a more recent study, healthy, young men were found to increase their food intake by about 25% following two days of receiving about 40% of their normal intake and by slightly less than 9% on the second day of recovery [10,11]. These findings are also consistent with the literature concerning the effects of skipping breakfast or mid-meal snacks. Skipping meals fails to result in an increase in energy intake sufficient to compensate for the reduction in energy intake [12].

Despite the statistically significant loss and recovery of body weight following a day of partial or complete food deprivation over the course of one week, care must be taken in interpreting these data in terms of body tissue change. The average daily energy intake during the one week baseline was approximately 2000 kcal. Imposing a one day fast, therefore, would create an energetic deficit of about 2000 kcal. Given the commonly accepted figure of the energy cost of weight loss of 7700 kcal per kg, a deficit of 2000 kcal would be expected to produce a loss of approximately 0.26 kg (2000 kcal/7700 kcal per kg) of body tissue, accounting for slightly more than 20% of the actual weight loss of 1.2 kg. By the same calculations, imposing the partial fast by allowing 800 kcal only accounted for 13.7% of the 0.76 kg weight loss. Most of the weight loss caused by the energy restriction probably consisted of a loss of gastrointestinal contents, glycogen, and body water.

However, the reduction in body weight following the partial and complete fast indicates that the participants did follow the instructions to not eat anything from sources outside of the study. This high compliance with the instructions is supported by the exit interviews which gave no indication that the participants did not completely comply with the study protocol. Therefore, it is unlikely that the lack of change in food intake following the partial and complete fast could

be attributed to participants "cheating" by eating outside the unit during the day of partial or complete fasting.

It is possible that we were unable to detect an increase in energy intake following the day of energy restriction because of an error in our measurement of energy intake. This explanation is unlikely for several reasons. First, the test-retest correlation between the weekly intake of individuals during baseline and after eating ad libitum during the testing phase was remarkably high ($r = 0.80$, $p < 0.001$). Similarly, the test-retest correlation of between the amount of food consumed on the day following ad libitum feeding day and the day following energy restriction or fasting was also highly significant ($r = 0.52$, $p = .01$ and $r = 0.56$, $p = 0.01$, respectively). Indeed, a power calculation of these data indicated that our measurements were sufficient to detect about a 20 kcal difference with a power of 0.8 and alpha set at 0.01.

Perhaps the best indication that the lack of an increase in food intake following a day of partial or complete food deprivation was not due to error in measurement can be seen in the identical slopes of the accumulated intakes (see Fig. 5) following the three conditions (eating ad libitum, energy restriction, or total fasting). Any difference in energy intake, even a small one, following any of the three conditions would be amplified by the cumulated intake function. In fact, the calculation of the total energy intake over the four days of recovery following the fasting and semi-fasting conditions was actually lower than following ad libitum eating – the opposite to what one would expect if compensatory overeating following energy restriction would have occurred.

Although direct measurement of energy expenditure was made in this study, it appears that the only explanation of how body tissue could be regained following a partial or complete fast without an increase in energy intake is a decrease in energy expenditure. It is possible to estimate the amount of depression in energy expenditure that would be necessary to cause the recovery of body weight without an increase in food intake by examining published literature. Although no studies have measured the reduction in metabolic rate following a single day of fasting until recovery, Dauncey [13] found that an energy deficit of 1121 kcal per day for two days produced a decrease in metabolic rate of 6.1% measured over the succeeding 24 h. de Boer et al. [14] reduced energy intake in overweight women by about 1000 calories for one day and observed a decrease in metabolic rate of 5.5% measured 24 h after the end of the dietary restriction. The only measurement of metabolic rate following a full fast was published by Weyer et al. [15], but they had subjects fasting for 48 h. This procedure produced a decrease in metabolic rate by 9% on the day following the fast. The best estimate, therefore, of the degree of depression in metabolic rate following a 24 h fast is about 7% or 140 kcal (7% of 2000 kcal). If metabolic rate were suppressed by 7%, it would take approximately 14 days for the participants to totally recover their body tissue by metabolic savings alone. It should be pointed out that if these estimates of reduced metabolic rate are accurate, then what appeared as recovery of body weight by day 5 was not full recovery of body tissue. Rather, the increased weight measure was obscured by increases in body water or intestinal contents which made the recovery of body weight appear earlier than it actually did.

One limitation of this study is that only one day of food restriction was examined. It is possible that with repeated days of food restriction, food intake may increase to compensate for the reduction in energy intake. However, there is a good indication from the literature that humans do not precisely compensate for energy restriction by increasing the energy intake even when confronted with repeated food restriction. Heilbronn et al. [16] examined the weights of people who alternated a day of fasting between a day of ad libitum intake for 22 days. Fig. 6 is a replot of their data.

This figure shows body weight at the end of both the fasting and the non-fasting days across the 22 days of the study. The variability in body weight on the non-fasting days is greater than the variability of

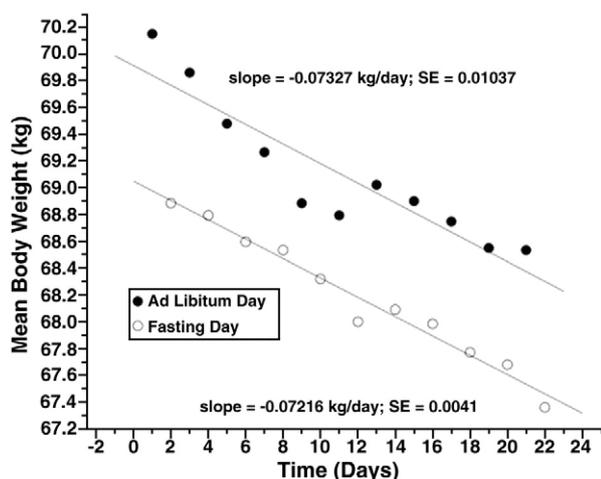


Fig. 6. Replot of daily body weight data of Hailbraun [16] measured across the 22 days of the study where days of fasting alternated between days of eating ad libitum.

weight at the end of a non-fasting day due to the fact that the weight data also reflects gastro-intestinal tracts, fluid content and glycogen content. However, the fact that the rate of decrease in body weight following a day of ad libitum eating is equal to the rate of decrease following a day of fasting indicates that little or no increase in food intake (adaptation) occurred in response to a day of fasting across the 11 repeated cycles of feeding and fasting.

It is interesting to note that the participants in the Heilbronn et al. [16] study complained that they did not like this kind of fasting–nonfasting regime and would not use it as a method of controlling their weight. Perhaps, instead of continuously alternating between fasting and non-fasting, people could better adjust to a fast or semi-fast if it were imposed only one or two times per week. The net effect will be a reduction in energy intake and a reduction in body weight.

Another limitation of the study is that the sample was limited to unrestrained eaters. It is possible that either unrestrained eaters or people whose body weight is reduced from their highest level – may react to deprivation differently than the subjects in the present study. Additional studies are needed to assess whether the conclusions reached by this study apply to the entire population.

Finally, it is important to consider the results of the present study on the recovery from food deprivation to our previous study on the recovery from overfeeding [17]. In that study participants were forced to overeat and gain weight for 13 days. Following the period of overfeeding, weight loss ensued, but it was not caused by any reduction in daily food intake. Mean daily intake returned to pre-overfeeding levels, even on the first day following overfeeding. We estimated that the weight loss during the recovery period could be accounted for an increase in metabolic rate of about 14%. Thus, in both overfeeding and underfeeding, the control of food intake in humans is not the primary mechanism responsible for the return of body weight to pre-perturbation levels. Rather changes in energy expenditure appear to be the dominant mechanism responsible for the regulation of body weight. Eating behavior appears to be more responsive to external, environmental cues, than internal physiological signals [18].

These data further suggest that the inability of people to maintain their lost weight after dieting may not be due to overeating. If the same metabolic processes that allowed recovery of body weight to occur under the present experimental conditions also operate over a longer time period, then a return to the consumption of daily energy intake to the amount consumed prior to dieting would be sufficient to allow their weight to recover without overeating. To sustain the weight loss, it is necessary to continually reduce energy intake. Perhaps, – regularly interspersing a day of fasting or food restriction within their weekly food cycle may allow people to maintain their reduced intake and thereby produce a sustained reduction in body weight.

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References

- [1] Levitsky DA. Putting behavior back into feeding behavior: a tribute to George Collier. *Appetite* 2002;38:143–8.
- [2] Polivy J. Psychological consequences of food restriction. *J Am Diet Assoc* 1996;96:589–92 quiz 93–4.
- [3] Anderson JW, Konz EC, Frederich RC, Wood CL. Long-term weight-loss maintenance: a meta-analysis of US studies. *Am J Clin Nutr* 2001;74:579–84.
- [4] Telch CF, Agras WS. The effects of short-term food deprivation on caloric intake in eating-disordered subjects. *Appetite* 1996;26:221–33.
- [5] Rolls BJ, Kim S, McNelis AL, Fischman MW, Foltin RW, Moran TH. Time course of effects of preloads high in fat or carbohydrate on food intake and hunger ratings in humans. *Am J Physiol* 1991;260:R756–63.
- [6] Agras WS, Telch CF. The effects of caloric deprivation and negative effect on binge eating in obese binge-eating disordered women. *Behav Ther* 1998;29:491–503.
- [7] Hetherington MM, Stoner SA, Andersen AE, Rolls BJ. Effects of acute food deprivation on eating behavior in eating disorders. *Int J Eat Disord* 2000;28:272–83.
- [8] Johnstone AM, Faber P, Gibney ER, Elia M, Horgan G, Golden BE, et al. Effect of an acute fast on energy compensation and feeding behaviour in lean men and women. *Int J Obes* 2002;26:1623–8.
- [9] Herman CP. Restrained eating. *Psychiatr Clin North Am* 1978;1:593–607.
- [10] Blom WA, Mars M, Hendriks HF, de Groot LC, Stafleu A, Kok FJ, et al. Fasting ghrelin does not predict food intake after short-term energy restriction. *Obesity (Silver Spring)* 2006;14:838–46.
- [11] Mars M, de Graaf C, de Groot LCPGM, Kok FJ. Decreases in fasting leptin and insulin concentrations after acute energy restriction and subsequent compensation in food intake. *Am J Clin Nutr* 2005;81:570–7.
- [12] Levitsky DA. The non-regulation of food intake in humans: hope for reversing the epidemic of obesity. *Physiol Behav* 2005;86:623–32.
- [13] Dauncey MJ. Metabolic effects of altering the 24-h energy-intake in man, using direct and indirect calorimetry. *Br J Nutr* 1980;43:257–69.
- [14] de Boer JO, Vanes AJH, Roovers LCA, Vanraaij JMA, Hautvast J. Adaptation of energy-metabolism of overweight women to low-energy intake studied with whole-body calorimeters. *Am J Clin Nutr* 1986;44:585–95.
- [15] Weyer C, Zozarova B, Ravussin E, Tataranni PA. Changes in energy metabolism in response to 48 h of overfeeding and fasting in Caucasians and Pima Indians. *Int J Obes* 2001;25:593–600.
- [16] Heilbronn LK, Smith SR, Martin CK, Anton SD, Ravussin E. Alternate-day fasting in nonobese subjects: effects on body weight, body composition, and energy metabolism. *Am J Clin Nutr* 2005;81:69–73.
- [17] Levitsky DA, Obarzanek E, Mrdjenovic G, Strupp BJ. Imprecise control of energy intake: absence of a reduction in food intake following overfeeding in young adults. *Physiol Behav* 2005;84:669–75.
- [18] Levitsky DA. The control of food intake and the regulation of body weight in humans. In: Harris RBS, Mattes RD, editors. *Appetite and food intake: behavioral and physiological considerations*. Boca Raton: CRC Press; 2008. p. 21–42.