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Effect of calorie restriction on subjective ratings of appetite

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Abstract

Background—Energy or calorie restriction (CR) has consistently been shown to produce weight loss and have beneficial health effects in numerous species, including primates and humans. Most individuals, however, are unable to sustain weight losses induced through reductions in energy intake, potentially due to increased hunger levels. The effects that prolonged CR has on subjective aspects of appetite have not been well studied. Thus, the present study tested the effect of 6 months of caloric restriction on appetite in healthy, overweight men and women.

Methods—Forty-eight overweight men and women with a body mass index (BMI; kg m^{-2}) between 25–29.9 took part in a 6-month study and were randomised into one of four groups: healthy diet (control); 25% CR; 12.5% CR plus exercise (12.5% increased energy expenditure; CR + EX); low-calorie diet [LCD; 3724 kJ day^{-1} (890 kcal day^{-1}) until 15% of initial body weight was lost, then maintenance]. Appetite markers (i.e. hunger, fullness, desire to eat, etc.) were assessed weekly during a fasting state.

Results—Body weight was significantly reduced in all three energy-restricted groups (CR = −10.4 ± 0.9%; CR + EX = −10.0 ± 0.8%; and LCD = −13.9 ± 0.7%), indicating that participants were adherent to their energy restriction regimen, whereas the healthy diet control group remained weight stable (control = −1.0 ± 1.1%). Despite these significant weight losses, appetite ratings of participants in the three energy-restricted groups at month 6 were similar to the weight stable control group.

Conclusions—CR regimens with low fat diets producing significant weight losses have similar effects on appetite markers over a 6-month time period compared to a weight stable control group.

Keywords

appetite; caloric restriction; hunger; satiety; visual analogue scale; weight loss

Introduction

Energy or caloric restriction (CR) has consistently been shown to produce weight loss, as well as have beneficial effects on the ageing process, in numerous species (Heilbronn & Ravussin, 2003). Most individuals, however, are unable to sustain weight losses induced through reductions in energy intake (Mann *et al.*, 2007), possibly due to compensatory mechanisms that signal the body to increase food intake or decrease energy expenditure in response to weight loss. For example, nutrient stimulated glucagon-like peptide 1 (GLP-1) release, a peptide hormone that influences satiety and reduces food intake, is reduced in obese individuals after

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6 weeks of energy-restricted weight loss (Adam & Westerterp-Plantenga, 2005). Additionally, leptin, an adipose derived hormone that decreases energy intake, is decreased in response to hypocaloric diets prior to changes in adiposity (Keim *et al.*, 1998; Yang & Barouch, 2007). Although these findings suggest that CR should significantly influence appetite (e.g. hunger and fullness), the effects that prolonged CR has on subjective aspects of appetite have not been well studied.

To date, most research examining the effect of CR on subjective ratings of appetite has focused on obese adults (Wadden *et al.*, 1997; Doucet *et al.*, 2003). For example, Doucet *et al.* (2003) found participants' desire to eat and hunger levels, both measured in a fasting state, were significantly increased in obese individuals after a 15-week weight loss programme involving energy restriction. By contrast, Wadden *et al.* (1997) found hunger levels were significantly reduced after the fifth week of treatment among obese women participating in a 48-week weight loss study. In that study, four different weight loss interventions were utilised (diet alone; diet plus aerobic training, diet plus strength training, and diet combined with aerobic and strength training), but all four groups were combined for the analysis of changes in hunger over time. Of importance, a weight stable control group was not included in either study mentioned above; thus, these studies do not inform about potential variations in hunger levels that occur over time among weight stable individuals.

Given the increasing prevalence of obesity and its associated negative health impact (Ogden *et al.*, 2006), there is a significant need for effective treatments. In studies that have examined predictors of weight regain after weight loss, higher levels of self-reported hunger have been found to predict weight regain (Pasman *et al.*, 1999), even after a period of successful weight loss maintenance (McGuire *et al.*, 1999). A better understanding of the influence of CR on hunger and satiety may assist in the development of interventions that promote long-term weight loss maintenance.

In addition to affecting body weight, CR has been shown to delay the onset of age-related diseases and extend lifespan in numerous species (Heilbronn & Ravussin, 2003). Preliminary research also indicates that CR has beneficial effects on the ageing process in primates (Kayo *et al.*, 2001; Bodkin et al., 2003), as well as biomarkers of ageing in overweight, but not obese, humans (Heilbronn *et al.*, 2006; Martin *et al.*, 2007). If research continues to find that CR has beneficial effects on health and ageing in nonobese humans, then the effect of CR on appetite will be a topic of increasing scientific importance. Such studies will provide critical information regarding the feasibility of CR as a strategy for nonobese individuals to improve health and extend lifespan.

To date, no study has examined the relationship between CR and appetite in an overweight, but not obese, sample, or whether the method of CR differentially impacts appetite while also including a weight stable control group. In the present study, we examined both of these questions in the context of a 6-month clinical trial involving three different CR groups and a weight stable control group. The study was an ancillary study of the CALERIE trial, which has been described in detail by Heilbronn *et al.* (2006). The primary objective of the present study was to investigate whether 6 months of CR affects appetite markers (hunger, fullness, desire to eat, satisfaction of appetite and prospective food consumption) in overweight adults. To date, the few studies that have examined the effect of CR on appetite have produced mixed results; therefore, we did not have specific hypotheses regarding group or within-group changes in appetite markers.

Materials and methods

Participants

Participants were 48 healthy, nonsmoking, overweight men and women with a body mass index (BMI; kg m^{-2}) in the range 25–29.9. All individuals volunteered to participate in a 6-month study investigating the effects of CR on biomarkers of ageing and metabolic adaptation. Potential participants were screened to ensure that there were no physiological or psychological contraindications to their participation in the study. A detailed description of participant characteristics, as well as inclusion and exclusion criteria, has been provided by Heilbronn *et al.* (2006). Twelve participants were randomised to each of the following treatment groups for the 6-month study: (i) control (weight maintenance diet); (ii) CR (25% CR based on baseline energy requirements); (iii) CR plus structured exercise (CR + EX; 12.5% CR plus 12.5% increase in energy expenditure via structured exercise); and (iv) low-calorie diet [LCD; 3724 kJ day^{-1} (890 kcal - day^{-1}) liquid formula diet until 15% of body weight is lost, followed by weight maintenance]. During the study, two participants withdrew (one LCD and one control); one for personal reasons and the other was lost to follow-up. Thus, the study sample comprised a total of 46 individuals.

Diet

Participants were provided with all of their food from baseline to week 12, and again from weeks 22–24. Information regarding the derivation of dietary prescriptions for each participant and group provided in detail elsewhere (Heilbronn *et al.*, 2006). From weeks 13–22, participants self-selected their diets based on their individual calorie prescriptions. All diets, except the LCD, were based on the American Heart Association recommendations (≤30% fat). The LCD was 3724 kJ day^{-1} (890 kcal -day^{-1}) (HealthOne, Health and Nutrition Technology, Carmel, CA, USA) given as five shakes containing 75 g of protein, 100 g of carbohydrate and 5 g bolus of fat per day. Once target weight loss (−15%) was achieved, participants in this condition were slowly fed an increasing energy intake level to maintain body weight.

Measures

Anthropometrics—Weight was measured each week in a hospital gown, after the participant had voided and fasted for 12 h. Baseline weight was calculated as the average of five weights taken over the 4-week baseline period (i.e. days 0, 7, 14, 21 and 28).

Visual analogue scale—Visual analogue scales (VAS) were used to measure the following appetite markers: (i) *Hunger*, (ii) *Fullness*, (iii), *Satisfaction of Appetite*, (iv) *Desire to Eat* and (v) *Prospective Food Consumption.* Previous research has shown that VAS ratings are highly correlated with actual food intake and have satisfactory reliability and validity (Flint *et al.*, 2000; Parker *et al.*, 2004).

Procedure

Participants completed VAS measurements in a fasting state before breakfast, between 07.00 h and 09.00 h, on a weekly basis during the center-based feeding portion of this 6-month study (baseline: week 11; weeks 22–23). When completing the VAS, participants were instructed to subjectively rate the intensity of their current state (i.e. ‘at that moment’) for a number of appetite markers by placing a cursor and clicking the mouse on a computerised 100-increment line representing the continuum from ‘not at all’ to ‘extremely’. Specifically, participants were asked to provide subjective ratings of their current state for the following appetite markers: (i) *Hunger* – ‘How hungry do you feel at this moment?’ (ii) *Fullness* – ‘How full does your stomach feel at this moment?’ (iii) *Desire to Eat* – ‘How strong is your desire to eat at this moment?’ (iv) *Satisfaction of Appetite* – ‘How satisfied do you feel at this moment?’ and (v)

Prospective Food Consumption – 'How much food do you think you could eat at this moment?' The ratings were sequential but separate (one rating per screen). Because participants were in a fasting state during VAS measurements, their level of reported hunger was thought to be at its highest point within each day.

Statistical analysis

For all analyses, the dependent variable was the change from baseline (month 6 – baseline) value for the following appetite markers: *Hunger, Fullness, Desire to Eat, Satisfaction of Appetite and Prospective Food Consumption*. Analysis of covariance was used to test for changes in appetite markers across groups, using baseline as the covariate. Baseline values of each appetite marker were based on the average of two VAS ratings made on days 21 and 28 of the baseline assessment period. Weekly ratings were then averaged to yield a mean value for each month (e.g. month 1 = average of VAS ratings during weeks 1–4). Because the sample sizes were relatively small in each of the four groups ($n = 12$), the results were also expressed in terms of effects sizes (ES). Generalised eta squared, an effect size measure, was used to express the proportion of variance in change scores accounted for by treatment (Olejnik & Algina, 2003). This measure of ES was selected because it is less affected by study design, can be compared across studies, is preferred when analysis of variance is used (Bakeman, 2005), and can be interpreted using Cohen's guidelines (Cohen, 1998), which suggest that ES of 0.02, 0.13 and 0.26 represent small, medium and large ES, respectively. All analyses were performed using SAS, version 8.2 (SAS Institute, Cary, NC, USA).

Results

Demographic characteristics of the participants are summarised in Table 1. The sample was predominantly Caucasian ($n = 34$; 70%); 12 participants were African-American (25%) and two participants were 'other' or unknown (5%). Weight loss by group for the present study sample was: control = −1.0 ± 1.1%; CR = −10.4 ± 0.9%; CR + EX = −10.0 ± 0.8%; and LCD = −13.9 ± 0.7% of initial body weight (Heilbronn *et al.*, 2006).

Changes in appetite markers

Examination of changes of appetite markers across 6 months indicated that these changes generally occurred during the first 2 months and then remained stable from months 3–6. Based upon this observation, we elected to analyse change scores from baseline to month 6, without regard for the changes observed earlier in the study. These change scores are summarised in Table 2. After controlling for baseline values, there were no significant between group differences in change scores (month 6 – baseline) on any measured appetite marker (*Hunger, Fullness, Desire to Eat, Satisfaction of Appetite or Prospective Food Consumption*; all *P*s > 0.30). Effect sizes (generalised eta squared) were small for all treatment groups, with group assignment accounting for no more than 5% of the variance in appetite changes. Significant changes, however, in some appetite markers were observed within specific groups and are described below. Table 2 presents change scores and percent change in each appetite marker at month 6 for all groups.

Hunger—Based on within group analyses, hunger levels did not significantly differ from baseline values in any group.

Fullness—Based on within group analyses, fullness levels did not significantly differ from baseline values in any group.

Desire to Eat—Ratings on the *Desire to Eat* marker were significantly higher than baseline values in the CR ($P < 0.01$) and LCD groups ($P = 0.05$) only.

Satisfaction of Appetite—Ratings on the *Satisfaction of Appetite* marker were significantly lower than baseline values at month 6 for the CR group only ($P < 0.01$).

Prospective Food Consumption—Ratings on the Prospective *Food Consumption* marker were significantly increased for the CR + EX ($P < 0.01$) and LCD groups ($P < 0.05$) only.

Discussion

The present study is the first to examine the impact of CR on changes in appetite markers in a nonobese population, as well as whether the method used to obtain CR [i.e. CR alone, CR + EX, or LCD of 3724 kJ day^{-1} (890 kcal day^{-1})] differentially impacts appetite over time. The CR and CR + EX groups underwent a 25% energy deficit, resulting in a weight loss of approximately 10% of initial weight, and the LCD group lost approximately 14% of their initial body weight during the first 3 months of the study and subsequently remained weight stable for the remaining 3 months. Despite these significant weight losses, appetite ratings of participants in the three CR groups generally resembled those of a weight stable, non-restricted control group. Of importance, previous studies examining the effects of energy restriction on appetite have not included a weight stable control group; thus, the present study is the first to investigate natural variation in appetite changes among weight stable individuals over time.

In animal studies, hunger levels are typically elevated after prolonged CR, even during periods of energy balance (Speakman & Hambly, 2007). Moreover, physiological satiety signals (e.g. GLP-1, leptin) are reduced after energy restriction in humans (Keim *et al.*, 1998; Adam & Westerterp-Plantenga, 2005), and higher levels of self-reported hunger have been associated with poor weight loss maintenance (McGuire *et al.*, 1999; Pasman *et al.*, 1999, 1999). Few studies, however, have directly tested the effect that energy restriction has on subjective hunger and satiety levels (Wadden *et al.*, 1997; Doucet *et al.*, 2003). Moreover, findings from studies performed to date have been mixed. The reason for these disparate findings is not clear, but factors such as study duration, participant characteristics and the method used to induce energy restriction may all play an important role. Thus, we were particularly interested in studying the effects of prolonged CR (achieved through three different methods) on self-reported hunger and fullness levels in overweight, but not obese, humans. For hunger, the three CR groups changed in a similar manner; additionally, the control group had a +8% change, which was similar to the change observed in the CR groups. Reported fullness levels changed in a similar manner to hunger levels. There were no significant treatment effects, but reported fullness levels were decreased in all groups (range = 12–26%).

Participants' reported *Desire to Eat* was significantly increased at month 6 in the CR and LCD groups only, but was also increased in the CR + EX and control groups, suggesting that all four dietary interventions may have increased *Desire to Eat* to some degree (range for all groups = 12–23%). Similarly, reported *Prospective Food Consumption* was significantly increased only in the CR + EX but was also higher than baseline values in the CR and control groups (range for all groups = 13–21%). These findings are in line with previous studies demonstrating that both *Desire to Eat and Prospective Food Consumption* were increased following 15 weeks of energy restriction and to an even greater extent after an 18-week low-fat diet and exercise follow-up programme (Doucet *et al.*, 2000). Ratings on the *Satisfaction of Appetite* marker were significantly lower than baseline values at month 6 for the CR group only, but were also decreased in the all other groups, including the weight stable control group (range for all groups = 12–30%). To our knowledge, the present study is the first to examine the effects of prolonged energy restriction on *Satisfaction of Appetite*; thus, this represents a novel finding of our study.

In general, the subjective appetite ratings of participants in the healthy diet control group changed in a similar manner to participants in the three treatment groups. The reason for these

subjective appetite changes is not clear, particularly because the participants in the healthy diet control group were weight stable throughout the study. This is the first study to report subjective appetite changes among weight stable individuals on a healthy diet. Thus, our findings may reflect the natural variation in appetite that occurs among individuals consuming a weight stable diet. It is also possible, however, that the demand characteristics of the present study contributed to the reported changes in subjective appetite ratings over time among participants in this group. For example, similar to participants in the three treatment groups, the participants in the healthy diet control group were provided with a study diet and were asked to report their hunger levels when in a fasted state in a clinic environment. Moreover, participants in all groups were aware that they were participating in a caloric restriction study.

Relative to previous studies, the present study had several strengths. First, no study to date has examined the impact of CR on appetite in a nonobese population. As such, the present study provides important information regarding the feasibility of CR as a strategy to improve health in nonobese populations. Second, the present study is the first to test whether three different methods of CR vary in terms of their impact on appetite. Third, the present study is the first to include a healthy diet weight stable control group when evaluating the impact of different methods of CR on appetite markers. Without inclusion of a control group, the effect that CR has on appetite markers cannot be fully determined. The additional strengths of the study include the frequent assessment of appetite ratings and close monitoring of energy intake and expenditure; adherence levels were found to be very good in all conditions, as demonstrated by the significant weight losses in the three CR conditions. Finally, retention rates were very high (96%), particularly given the demands of the present study.

The present study also had a number of potential limitations. First, the VAS data were collected during feeding periods at the research center only and were not collected during the period of self-selected food intake (weeks 12–21). However, this may also be viewed as a strength because adherence to energy intake recommendations were closely monitored during the feeding periods at the research center. Second, the sample size for the present study was small, which decreased statistical power to detect significant interaction effects (i.e. treatment by time); thus, our results should be interpreted with caution. Nevertheless, effect size calculations (generalised eta squared) indicated that no more than 5% of the variance in appetite rating change could be attributable to treatment. Additionally, our findings are limited to the first 6 months of CR, which corresponds to the weight reduction phase rather than weight maintenance phase in most obesity studies. However, participants in the LCD condition were weight stable for the last 3 months of the study (half of the study duration) and their appetite ratings were similar to the other two CR groups. Future studies are warranted to determine whether appetite markers change with long-term weight maintenance, as well as whether changes in appetite markers predict weight regain. Another potential limitation may have been the inherent demand characteristics of the study, which may have affected reported changes in appetite ratings among participants in all groups.

In summary, there were no significant treatment effects on subjective ratings of appetite, and the effect sizes were small for all measured appetite markers. Participants' *Hunger* and *Fullness* ratings in the three intervention groups did not differ from baseline levels and were similar to participants in the healthy diet weight stable control group, despite significant weight losses. Future studies are needed to further explore the viability of CR, as well as different methods of CR, to promote healthy weight management, as well as a strategy to potentially achieve other health benefits.

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Conflict of interests, source of funding and authorship

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SDA drafted the paper, as well as interpreted the results of data analysis. HH conducted all data analyses. EY and CKM contributed to the draft of the paper, as well as the interpretation of results of data analysis. ER and DAW contributed to the design of the study, the draft of the paper and the interpretation of results of the data analysis. All authors critically reviewed the manuscript and approved the final version submitted for publication.

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Table 1

Baseline characteristics of participants (completers) by treatment condition

	Control	CR	CR + EX	LCD
n	11 (five males)	12 (six males)	12 (five males)	11 (six males)
Age (year)	37.0 (7.0)	39.0 (5.0)	36.0 (6.0)	38.0 (8.0)
Weight (kg)	81.7 (8.9)	80.9 (11.4)	81.9 (10.5)	82.0 (10.8)
Body mass index (kg m^{-2})	27.8 (2.0)	27.8 (1.4)	27.5 (1.6)	27.7 (1.8)

CR, calorie restriction; CR + EX, calorie restriction plus exercise; LCD, low calorie diet.

Values are expressed as the mean (SD).

Table 2

Change scores and *P*-values for analyses that tested whether the groups differed significantly on change scores at month 6

	Baseline value; mean (SD)	Change from baseline; mean (SD)	Percent change	Month 6 change from baseline within each condition (*P*-value)	Month 6 treatment effects (*P*-value)	Effect size (generalized eta squared)
Hunger						
CR	63.5 (5.8)	8.4 (4.9)	+13	0.09	0.95	0.02
CR + EX	59.6 (7.4)	6.6 (4.9)	+11	0.18		
LCD	60.9 (5.7)	8.2 (5.1)	+13	0.12		
Control	58.6 (7.9)	4.6 (5.1)	+8	0.37		
Fullness						
CR	32.3 (6.5)	8.5 (4.8)	−26	0.08	0.87	0.02
CR + EX	33.4 (5.8)	4.7 (4.8)	−14	0.32		
LCD	24.2 (4.0)	2.9 (5.0)	−12	0.56		
Control	31.3 (4.5)	4.7 (5.0)	−15	0.35		
Desire to Eat						
CR	64.0 (6.8)	14.6 (4.4)	+23	0.002	0.64	0.05
CR + EX	63.2 (7.7)	7.3 (4.4)	+12	0.10		
LCD	66.2 (6.5)	9.2 (4.6)	+14	0.05		
Control	58.4 (7.3)	8.4 (4.6)	+14	0.07		
Satisfaction of Appetite						
CR	43.3 (7.9)	15.9 (5.4)	−37	0.005	0.50	0.05
CR + EX	33.8 (5.8)	10.1 (5.4)	−30	0.07		
LCD	32.1 (5.9)	3.8 (5.6)	−12	0.50		
Control	43.5 (6.1)	9.7 (5.6)	−22	0.09		
Prospective Food Consumption						
CR	60.4 (4.7)	7.7 (4.4)	+13	0.09	0.33	0.04
CR + EX	62.4 (6.0)	12.9 (4.5)	+21	0.006		
LCD	64.9 (3.9)	9.5 (4.7)	+15	0.05		
Control	55.0 (6.5)	7.2 (4.7)	+13	0.14		

CR, caloric restriction; CR + EX, caloric restriction plus exercise; LCD, low calorie diet.

Effect sizes, which represent the proportion of variance in change scores accounted for by treatment, are also provided.