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Impact of dose-response calorie reduction or supplementation of a covertly manipulated lunchtime meal on energy compensation☆

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HIGHLIGHTS

- Human sensitivity to stepwise differences in energy content of 5 meals was examined.
- Test lunches were matched for palatability, sensory properties, and volume.
- There was no compensation for “missing” or “added” calories at subsequent meals.
- Energy compensation in response to both underfeeding and overfeeding is imprecise.
- Covertly manipulated meals may promote either positive or negative energy balance.

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ABSTRACT

Numerous studies have examined energy compensation following overfeeding regimes whereas much less is known about the impact of acute underfeeding on energy compensation and fewer still have compared energy reduction and addition in the same group of individuals. This study compared the effects of consuming lunches with varying energy content (7.2-fold difference) on subsequent energy intake. A total of 27 healthy males took part in this randomized, crossover study with five treatments: 163 kcal (very low energy meal, VLEM), 302 kcal (low energy meal, LEM), 605 kcal (control), 889 kcal (high energy meal, HEM), and 1176 kcal (very high energy meal, VHEM) served as a noodle soup. Participants were instructed to consume a standardized breakfast in the morning and they were provided with one of the five treatments for lunch on non-consecutive test day. Test lunches were matched for palatability, sensory properties, and volume. Participants were provided with an afternoon snack and ad libitum dinner on each test day and recorded food intake for the rest of the day. Appetite ratings were measured at regular intervals. As the energy content of treatments increased, participants' hunger, desire to eat, and prospective consumption decreased significantly whereas fullness increased significantly. However, no significant difference in subsequent meal intake was found between the treatments ($P = 0.458$): 1003 kcal VLEM, 1010 kcal LEM, 1011 kcal control, 940 kcal HEM, and 919 kcal VHEM. Total daily energy intake was statistically significantly different between the treatments ($P < 0.001$) and was varied directly with the energy content of the lunchtime meal. Despite the large difference in energy content between the treatments, participants did not compensate for the “missing calories” or “additional calories” at subsequent meals. These results suggest that covertly manipulated, equally palatable, sensory and volume matched meals have the potential to promote either positive or negative energy balance if the effects seen in this single meal study are sustained.

1. Introduction

Obesity results from sustained periods of positive energy balance and is the consequence of proportionately small deviations between energy needs and energy intake. Humans eat in response to their food environment and are frequently reliant on sensory, labeling or volume cues to gauge the energy content of the foods being consumed [1–3]. Numerous overfeeding studies have consistently demonstrated that spontaneous reductions in energy intake do not occur following a

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period of overfeeding, and can result in sustained positive energy balance and weight gain over time [4–7]. Many dietary strategies for weight loss are based on restricting food intake or reducing the calorie content of foods to produce large reductions in daily energy intake. However, long-term compliance to these diets and weight loss maintenance tends to be poor [8–11]. After many years of recommending reductions in fat and carbohydrate intakes, the general consensus is that total 'energy' content rather than a specific macronutrient target could be the key to reducing energy intake and shifting energy balance [12, 13].

Several food industries have signed a pledge to reduce the calorie content of their foods as part of their corporate social responsibility [14]. However, reducing the calorie intake by removing fat or sugar or by reducing portion size from foods may be challenging, as the calorie sources in a meal drive palatability, food purchase and consumption [15,16]. Recent advances in our understanding of sensory cues and satiation now create the opportunity to reduce calorie content while maintaining many of the sensory cues that promote palatability and satiation [2]. In addition, many attempts to reduce calorie content in the past have focused on arbitrary calorie reduction targets based on formulation, cost or clinical targets (i.e. very low calorie diets) [10,11,17,18], with little empirical understanding of how stepwise calorie reduction or addition influences re-bound hunger or energy compensation at the next meal.

Previous researchers have studied the effect of consuming different energy content of liquid preloads (0 kcal, 300 kcal, 600 kcal) on subsequent food intake 2 h after preload consumption [19]. Subsequent food intake was 1475 kcal after 0 kcal preload, 1154 kcal after 300 kcal preload, and 1056 kcal after 600 kcal preload. There was a marked difference in subsequent food intake between 0 and 300 kcal preloads (321 kcal), compared to 300 and 600 kcal preloads (98 kcal), despite the relative difference in both cases (0 and 300 kcal vs. 300 and 600 kcal) being identical. This suggests there could be a "calorie threshold", above which our basic physiological energy needs are met and there is much less rebound hunger or acute energy compensation.

While responses to overfeeding have been studied extensively, only a relatively small number of studies have been specifically designed to understand energy intake regulation in response to short-term energy reduction [20,21] and fewer still have compared energy reduction and addition in the same group of individuals [22–24]. These studies have typically found only partial compensation when energy content is manipulated, resulting in an acute net deficit in overall energy intake [20, 21]. Earlier research on underfeeding and overfeeding within the same small group of individuals ($n \leq 16$), reported slightly better compensation when participants were underfed than when overfed, though overall energy compensation remained poor [22–24]. However it remains unclear whether stepwise changes in meal calorie content around a baseline energy requirement (i.e. a "calorie threshold") would be perceived, and to what extent the quantity of the missing or added calories would be compensated for. The current study seeks to understand human sensitivity to stepwise differences in energy content of a realistic lunchtime meal (ranging from 163 to 1176 kcal), and the impact this has on energy intake within the same day.

2. Material and methods

2.1. Participants

Twenty seven healthy young lean males were recruited from the general public of Singapore through advertisements placed around the National University of Singapore campus (Table 1). The study inclusion criteria were healthy males aged between 21 and 40 years with normal BMI (18.5 to 25.0 kg/m^2). The exclusion criteria were individuals who were taking any drug known to affect appetite, were currently dieting, had allergies to any ingredient in the test meal, and anyone whose body weight had changed more than 5 kg in the past 12 months. In choosing only men and tightly controlling the inclusion criteria for our study, we focused our comparison on ability to detect energy differences between the lunch meals rather than comparing gender differences in caloric compensation. In addition, previous literature suggests that the menstrual cycle of females may play a role in energy intake and basal metabolic rate [25–27], therefore only males were included in this study. Participants were non-restrained eaters and non-smokers. The mean DEBQ restraint score was 2.51 ± 0.70. Only one participant reported eating relatively slowly, about half of the study participants reported eating at medium rate, ten participants reported eating relatively fast, and two participants reported eating very fast.

Table 1
Characteristics of study participants ($n = 27$).

	Mean ± s.d.
Age (years)	25.76 ± 2.89
Height (cm)	171.8 ± 6.2
Weight (kg)	64.12 ± 6.33
Body mass index (kg/m^2)	21.66 ± 1.63
Fat (%)	15.40 ± 4.31
Waist circumference (cm)	73.47 ± 4.86
Hip circumference (cm)	91.68 ± 4.25
Basal metabolic rate (kcal)	1533 ± 131
Fat mass (kg)	10.02 ± 3.46
Fat free mass (kg)	54.02 ± 4.48
Total body water (kg)	36.60 ± 3.44
Dentures (no. %)	1 (3.7%)
Sinus trouble (no. %)	4 (14.8%)

Values are mean ± s.d. unless indicated otherwise.

This study was approved by Singapore National Healthcare Group Domain Specific Review Board. All participants gave informed consent. The trial was registered with the Australia New Zealand Clinical Trials Registry (number: ACTRN12615000902594).

2.2. Design

This study was carried out using a randomized, crossover design with five treatments. The treatments were five ramen noodle soups with different energy contents that were served as a lunchtime meal: 163 kcal (very low energy meal, VLEM), 302 kcal (low energy meal, LEM), 605 kcal (control), 889 kcal (high energy meal, HEM), and 1176 kcal (very high energy meal, VHEM) (1 kcal = 4.186 kJ). A recent study reported that order of presentation of preload was a significant predictor of accuracy in energy compensation in adults [28], hence all of the participants in the present study received the control test meal during their first visit. Following this, half of the participants received the calorie reduction meal (VLEM or LEM) and the other half of the participants received the calorie increment meal (HEM or VHEM) during their second visit. The order was switched during the third visit, whereby participants who received the calorie reduction meal were given calorie increment meal during the third visit and vice versa. Thus, participants had equal chance of being exposed to either a high or a low energy test meal first. A washout period of a minimum of five days was required between the test sessions in order to prevent any carry-over effects. A cover story was used for this study, in which all participants were told that the objective of the study was to investigate the effect of food on mood.

2.3. Procedure

All potential participants underwent a screening session to provide informed consent and complete a screening questionnaire to determine their eligibility to participate. Participants were instructed to fast for a minimum of 10 h before the screening session. Anthropometric measurements were recorded which included height and weight (Seca 763 Digital Scale), waist and hip circumferences (luftkin W606PM measuring tape), and body composition analyzed using bioelectrical