Research report

Capsaicin increases sensation of fullness in energy balance, and decreases desire to eat after dinner in negative energy balance ☆

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Abstract

Addition of capsaicin (CAPS) to the diet has been shown to increase satiety; therefore, CAPS is of interest for anti-obesity therapy. We investigated the effects of CAPS on appetite profile and ad libitum energy intake in relation to energy balance. Fifteen subjects (seven women and eight men, age: 29.7 ± 10.8yrs, BMI: 23.3 ± 2.9 kg/m²) underwent four conditions in a randomized crossover design in 36 hour sessions in a respiration chamber; they received 100% of their daily energy requirements in the conditions "100%Control" and "100%CAPS", and 75% of their daily energy requirements in the conditions "75%Control" and "75%CAPS", followed by an ad libitum dinner. In the 100%CAPS and 75%CAPS conditions, CAPS was given at a dose of 2.56 mg (1.03 g of red chili pepper, 39,050 Scoville heat units) with every meal. Satiety (P < 0.05) and fullness (P = 0.01) were measured every waking hour and before and after every meal using visual analogue scales, and were higher in the 100%CAPS versus 100%Control condition. After dinner desire to eat, satiety and fullness did not differ between 75%CAPS and 100%Control, while desire to eat was higher (P < 0.05) and satiety (P = 0.06) and fullness (P = 0.06) tended to be lower in the 75%Control versus 100%Control condition. Furthermore, ad libitum intake (P = 0.07) and overconsumption (P = 0.06) tended to decrease in 100%CAPS versus 100%Control. In energy balance, addition of capsaicin to the diet increases satiety and fullness, and tends to prevent overeating when food intake is ad libitum. After dinner, capsaicin prevents the effects of the negative energy balance on desire to eat.

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Introduction

Obesity is the result of an energy imbalance that develops when energy intake exceeds energy expenditure. Obesity raises the risk of developing Type 2 Diabetes, cardiovascular diseases and several cancers (Haslam & James, 2005). Capsaicin (CAPS) is the major pungent principle of red chili pepper, which limits energy intake while it contains only negligible amounts of energy itself (Ludy & Mattes, 2011; Westerterp-Plantenga, Smeets, & Lejeune, 2005; Yoshioka et al., 1999). Therefore, CAPS might be an interesting target for anti-obesity therapy. To quantify the pungency of hot peppers, the Scoville test is used; the number of Scoville heat units (SHU) indicates the amount of CAPS present in the pepper. The CAPS level in peppers can vary from plant to plant. If a pepper contains 50,000 SHU, this means that its alcoholic extract needs to be diluted 1:50,000 to be pungent on the human tongue (Szallasi & Blumberg, 1999). Red chili pepper can be ingested orally or in capsule form. In a previous study on the relative oral and gastrointestinal contribution to capsaicin-induced effects on food intake, the decrease in energy intake was larger when red chili pepper was ingested orally compared with administration in capsule form. So, oral exposure to red chili pepper is more effective to achieve the maximum effect (Westerterp-Plantenga et al., 2005).

Several human studies have shown that the addition of CAPS to a diet enhances anorexigenic sensations, including satiety and fullness in energy balance (Smeets, Janssens, & Westerterp-Plantenga, 2013; Westerterp-Plantenga et al., 2005). Moreover, CAPS has been reported to suppress orexigenic sensations, it might decrease desire to eat (Ludy & Mattes, 2011) and hunger (Westerterp-Plantenga et al., 2005) in energy balance as well as in positive energy balance (Reinbach, Smeets, Martinussen, Moller, & Westerterp-Plantenga, 2009). In addition, several studies have shown that CAPS...
decreases *ad libitum* food intake (Ludy & Mattes, 2011; Westerterp-Plantenga et al., 2005; Yoshioka et al., 1999). The exact mechanism of action is not fully understood; however, CAPS has been shown to increase concentrations of the anorexigenic hormone glucagon-like peptide 1 and to decrease concentrations of the orexigenic hormone ghrelin (Smeets & Westerterp-Plantenga, 2009).

Furthermore, a study in rats using a diet containing CAPS has shown that CAPS causes an increase in catecholamine secretion from the adrenal medulla (Watanabe, Kawada, Yamamoto, & Iwai, 1987). This catecholamine secretion is caused by activation of the central nervous system (Watanabe, Kawada, Kurosawa, Sato, & Iwai, 1988). There is an association between sympathetic nervous system (SNS) activity and food intake behavior; food intake decreases when SNS activity increases (Russek et al., 1987). The increase in SNS activity after ingestion of CAPS suggests that the reduction in energy intake could be due to the anorexigenic effect of catecholamines (Yoshioka et al., 1999).

Yoshioka et al. (1999) found that the addition of red chili pepper to breakfast decreased the protein and fat intake at lunch time; these beneficial effects of CAPS on food consumption were observed when the meals had a high fat content (energy % protein/fat/carbohydrate: 15/45/40). It still is necessary to assess whether there is a beneficial effect when CAPS is added to meals with a normal protein, fat and carbohydrate content (energy % protein/fat/carbohydrate: 15/30/55). Furthermore, the study of Yoshioka et al. (1999) was conducted in Asians with relatively high doses of red chili pepper (10 g of red chili pepper per meal). There is a difference in maximum tolerable dose of red chili pepper between Japanese and Caucasians. This difference in tolerable dose is due to the difference in habitual red chili pepper consumption. In many Asian countries, red chili pepper is more common in the food pattern. For example, the average CAPS consumption in India is 25–200 mg/day while the average daily consumption in Europe is estimated to be 1.5 mg (Astrup et al., 2010). We investigated the effect of CAPS in Caucasians and with lower doses of red chili pepper (1.03 g of red pepper per meal). For weight-reduction strategies, it is necessary to investigate whether these effects of CAPS are still present during a moderate energy deficit. Since CAPS supplementation adds only negligible amounts of energy to food intake while it may enhance anorexigenic sensations and suppress orexigenic sensations, at least in energy balance, it is of importance to study whether these characteristics may be used as a concept for prevention of the yo-yo effect when entering negative energy balance. Yo-yo effect (or weight cycling) is the principle of repeated weight loss and regain (Brownell, Greenwood, Stellar, & Shrager, 1986). Normally, introduction of a negative energy balance by reducing energy intake causes an increase in appetite (Doucet et al., 2000). We assessed whether CAPS supplementation versus control during negative energy balance would counteract the normal increase in appetite. Taken together, we investigated whether there is an effect of CAPS on appetite profile and *ad libitum* energy intake in Caucasians when 1.03 g of red pepper is added to meals with a normal fat and normal protein content in a 25% negative energy balance.

**Methods**

**Subjects**

Nineteen healthy Caucasian subjects, aged between 18 and 50 years and a body mass index (BMI) between 20 and 30 kg/m² were recruited for this study. Subjects were recruited by advertisements in local newspapers and on notice boards at Maastricht University. All subjects underwent a medical screening, including anthropometric measurements, and questionnaires related to health, smoking behavior, use of medication, use of dietary supplements, alcohol and caffeine consumption, physical activity, habitual red chili pepper intake, eating behavior, mood and anxiety.

The inclusion criteria, besides an age between 18 and 50 years and a BMI between 20 and 30 kg/m², were good health, non-smoking, not using dietary supplement and medication except for oral contraceptives in women, not using a more than moderate amount of alcohol (less than 10 alcoholic drinks (10 g alcohol per drink) per week) or caffeine-containing beverages (less than 2 cups per day). Subjects had to be weight stable (weight change < 3 kg during the last 6 months) and dietary unrestrained. The Three Factor Eating Questionnaire was used to determine eating behavior (Stunkard & Messick, 1985). Only non-restrained eaters (<10 scores on factor 1), these are persons who are not consciously occupied with food or who are caloric restricted, were selected (Stunkard & Messick, 1985). Subjects had to be lightly or moderately active (1–5 hours moderate exercise per week) and used to consuming spicy foods on a regular basis (1–2 days per week, in a low dosage with one meal/day). In general, they consumed red chili pepper once per week (mean intake: 0.25–0.5 g of dried red pepper or 1–2 g of fresh red pepper). Pregnant or lactating women were also excluded. Individuals with allergies for the food items used in the study were excluded from participation.

This study was conducted according to the guidelines laid down in the Declaration of Helsinki, and all procedures involving human subjects were approved by The Medical Ethics Committee of the Academic Hospital in Maastricht. The study was conducted in the metabolic unit of Maastricht University, department of Human Biology and was registered as follows: ISRCTN, registration number NTR2944.

**Subject characteristics**

Body weight was measured using a digital balance and height by a wall-mounted stadiometer. BMI was calculated as body weight (kg) divided by height (m) squared. The deuterium dilution method according to the Maastricht protocol (Lichtenbelt, Westerterp, & Wouters, 1994) was used to measure total body water (TBW). The subjects were asked to collect a urine sample in the evening just before drinking a deuterium-enriched water solution. After ingestion of this solution, the subject went to bed, and no additional consumption was allowed. The following morning, another urine sample was collected. The dilution of the deuterium isotope is a measure of the TBW of the subject. Fat mass (FM) was calculated as body weight minus TBW divided by the hydration factor 0.73. Additionally, fat mass was determined by BodPod measurements (air displacement plethysmography) (Plasqui, Soenen, Westerterp-Plantenga, & Westerterp, 2011). Fat mass index (FMI) was calculated by FM (kg) divided by height (m) squared. BMI, FM (%) and FMI were used to define body composition. Waist and hip circumference were determined in standing position by a tape measure. Waist circumference was measured at the smallest circumference between rib cage and iliac crest, and hip circumference at the level of the spinia iliaca anterior superior. Accordingly, waist-to-hip ratio was calculated by dividing waist by hip circumference. Waist-to-hip ratio was used to define different patterns of body fat distribution (Table 1).

**Study protocol**

The study had a single-blinded, randomized crossover design with four randomly sequenced experimental conditions. Subjects underwent four 36 hour sessions in a respiration chamber (Janssens, Hursel, Martens, & Westerterp-Plantenga, 2012). Two days prior to each session, subjects were provided with a standardized diet to consume at home in order to be fed in energy balance (energy % protein/fat/carbohydrate: 15/30/55), and to receive the same macronutrient proportions as during the experiment. The energy intake level was estimated as such that subjects were not in a positive or a negative energy balance before they entered the respiration
chamber. Subjects were instructed to maintain their habitual activity level and were asked to abstain from alcohol consumption on the two days before each visit. Furthermore, they were asked not to drink caffeine after 22:00 hours on the day before each visit. The four test sessions were conducted at least one week apart for male subjects and four weeks apart for female subjects to prevent possible treatment-induced effects and to take eventual effects of menstrual cycle phase on energy intake in women into account. The results on energy expenditure and substrate oxidation are published elsewhere (Janssens et al., 2013).

Energy intake and food choice

Subjects were fed in energy balance during two days before the test sessions. Subject specific daily energy requirement was calculated based on basal metabolic rate, which was individually calculated with the equation of Harris–Benedict (Harris & Benedict, 1918), and multiplied by a physical activity level (PAL) of 1.7. This PAL value of 1.7 represents the average PAL of modern humans, which ranges from 1.5 to 2.0 (Westerterp, 2008). In our population in the south of the Netherlands, the PAL value of 1.7 is the mean (range 1.6–1.8) of the subjects, with the subject characteristics assessed in the present study. In the respiration chamber daily energy requirements were calculated based on a PAL of 1.35. The respiration chamber is a 14 m³ room; in this chamber subjects are only able to perform activities such as sitting, reading, watching television, and using the computer. By experience, the mean PAL of the subjects in the respiration chamber is 1.35. Subjects received 100% of their daily energy requirements in the conditions “100%Control” and “75%CAPS”, and received 75% of their daily energy requirements in the condition “75%Control” and “75%CAPS”. Negative energy balance in both 75%Control and “75%CAPS” conditions was calculated by energy intake minus total energy expenditure. The respiration chamber is about 1350–4000 mg capsicum with 0.25% CAPS (40,000 SHU). In the CAPS conditions, CAPS was given at a dose of 2.56 mg (1.03 g of red chili pepper, 39.050 SHU) with every meal. This dosage was based upon the maximal dosage given in previous studies (Lejeune, Kovacs, & Westerterp-Plantenga, 2003; Smeets & Westerterp-Plantenga, 2009; Westerterp-Plantenga et al., 2005). Divided over three meals, a daily total dose of 7.68 mg CAPS was consumed by the subjects. Preceding the study in the respiration chamber, several tests concerning pungency and spiciness were conducted using an anchored 100-mm visual analogue scales (VAS) (Flint, Raben, Blundell, & Astrup, 2000).In a pretest, several food items were tested in combination with different doses of red chili pepper. Before the dosage of red chili pepper in the food was determined, the pleasantness of taste, spiciness and pungency of different food products with red chili pepper were assessed to determine whether the amount of red chili pepper was tolerable. Based upon this pre-study, the products we chose to offer during the experiment were breakfast drink (Hero, breakfast drink original) with red chili pepper concentration of 2.0 g/L, pâté (Kips, cremenapaté) with 1.0 g red chili pepper/30 g, tomato juice (Appelsientje, Zontaam) with 2.0 g red chili pepper/l and pizza (Albert Heijn, cheese-tomato) containing 2.0 g red chili pepper/300 g. The given dose of each component did not exceed the maximum tolerable dose among our subjects. The ratings concerning the spiciness and pungency of these products with red chili pepper varied between 50 and 80 mm on the VAS; these scores represent a very spicy solution, but tolerable (Westerterp-Plantenga et al., 2005). Subjects were allowed to drink water ad libitum during their stay in the respiration chamber. Subjects recorded water intake using a measuring jug.

Appetite profile

Appetite profile (hunger, fullness, satiety and desire to eat) was measured using VAS (Flint et al., 2000). During each 36 hour session, these questionnaires were completed every waking hour, and before and after every meal. The appetite VAS data are given as area under the curve (AUC). AUC is the area above the baseline, calculated by the conventional trapezoid rule.

Furthermore, subjects completed questionnaires on pleasantness of taste, heat sensation, pungency and spiciness of the food after every meal. The scale was anchored from “not at all” on the left to “extremely” on the right.

Ad libitum meal

On the second day of the stay in the respiration chamber, pizza (AH, cheese-tomato, 0.9 MJ per 100g; energy 15% protein/carbohydrate/fat: 15/50/35) was provided for dinner ad libitum and was weighed before it was offered to the subjects. After 30 minutes, the leftover of the pizza was weighed again; then the amount of pizza consumed was calculated.

Overconsumption and overcompensation

Overconsumption for the 100%CAPS and the 100%Control conditions and overcompensation for the 75%CAPS and 75%Control conditions were calculated as the difference between the ad libitum meal and 100% of the daily energy requirement expressed as a percentage of the daily energy requirement.

Data analysis

The Statistical Package for the Social Sciences 20.0 (SPSS Inc, Chicago, IL) was used to perform univariate analyses. Repeated-measures ANOVA was used to determine possible differences in ad libitum energy and water intake, appetite profile, overconsumption and overcompensation between the four conditions. ANOVA repeated measures with sex as covariate was used to determine

Table 1

Subject characteristics.

<table>
<thead>
<tr>
<th></th>
<th>Male (n = 8)</th>
<th>Female (n = 7)</th>
<th>Total (n = 15)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>26.8 ± 8.4</td>
<td>33.0 ± 12.9</td>
<td>29.7 ± 10.8</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.82 ± 0.05</td>
<td>1.65 ± 0.05</td>
<td>1.74 ± 0.10</td>
</tr>
<tr>
<td>Body weight (kg)</td>
<td>79.8 ± 10.0</td>
<td>61.2 ± 10.3</td>
<td>71.2 ± 13.7</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>24.0 ± 2.6</td>
<td>22.4 ± 3.1</td>
<td>23.3 ± 2.9</td>
</tr>
<tr>
<td>WHR</td>
<td>0.80 ± 0.04</td>
<td>0.69 ± 0.04</td>
<td>0.75 ± 0.07</td>
</tr>
<tr>
<td>FM (kg)</td>
<td>14.6 ± 6.6</td>
<td>18.8 ± 6.0</td>
<td>16.6 ± 6.5</td>
</tr>
<tr>
<td>FFM (kg)</td>
<td>65.3 ± 6.9</td>
<td>42.4 ± 4.8</td>
<td>54.6 ± 13.1</td>
</tr>
<tr>
<td>Body fat (%)</td>
<td>17.8 ± 7.1</td>
<td>30.1 ± 4.5</td>
<td>23.6 ± 8.6</td>
</tr>
<tr>
<td>TFEQ F1</td>
<td>2.5 ± 2.6</td>
<td>3.1 ± 2.9</td>
<td>2.8 ± 2.7</td>
</tr>
<tr>
<td>TFEQ F2</td>
<td>4.9 ± 1.2</td>
<td>5.4 ± 3.4</td>
<td>5.1 ± 2.4</td>
</tr>
<tr>
<td>TFEQ F3</td>
<td>4.1 ± 4.3</td>
<td>3.9 ± 3.4</td>
<td>4.9 ± 3.9</td>
</tr>
</tbody>
</table>

BMI: Body mass index; WHR: Waist-to-hip ratio; FM: Fat mass; FFM: Fat free mass; TFEQ: Three Factor Eating Questionnaire; F1: cognitive restraint; F2: disinhibition; F3: hunger.

The TFEQ measures three different factors of human eating behavior. Subjects were Caucasian, and from the surrounding area of Maastricht, the Netherlands. Values are means with their standard deviations (SD).
Table 2
Area Under Curve of hunger, fullness, satiety and desire to eat (mmVAS × 36 h) during the four conditions.

<table>
<thead>
<tr>
<th></th>
<th>100%CAPS</th>
<th>100%Control</th>
<th>75%CAPS</th>
<th>75%Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hunger</td>
<td>67674.5 ± 3192.5&lt;sup&gt;a&lt;/sup&gt;</td>
<td>73741.8 ± 3541.6&lt;sup&gt;a&lt;/sup&gt;</td>
<td>88216.5 ± 3889.0&lt;sup&gt;b&lt;/sup&gt;</td>
<td>87299.8 ± 3768.4&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Fullness</td>
<td>105976.6 ± 3378.2&lt;sup&gt;a&lt;/sup&gt;</td>
<td>99522.3 ± 2983.3&lt;sup&gt;b&lt;/sup&gt;</td>
<td>84663.5 ± 2327.7&lt;sup&gt;a&lt;/sup&gt;</td>
<td>91145.7 ± 2820.9&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Satiety</td>
<td>118185.3 ± 3677.9&lt;sup&gt;a&lt;/sup&gt;</td>
<td>101157.8 ± 3051.4&lt;sup&gt;b&lt;/sup&gt;</td>
<td>89137.5 ± 2772.8&lt;sup&gt;a&lt;/sup&gt;</td>
<td>92689.8 ± 3023.8&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Desire to eat</td>
<td>72360.9 ± 3270.9&lt;sup&gt;a&lt;/sup&gt;</td>
<td>83546.7 ± 3763.3&lt;sup&gt;b&lt;/sup&gt;</td>
<td>96834.5 ± 3982.0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>99366.8 ± 4187.2&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

Values are means with their standard deviations (SD).
<sup>a,b</sup>Mean values within a row with unlike superscript letters were significantly different P < 0.05 (repeated measures ANOVA), n = 15.

possible differences between male and female subjects. Post hoc comparisons were made using Bonferroni. All statistical tests are two-sided, and differences are considered statistically significant if P < 0.05. Values are expressed as means and standard deviations or standard errors. Data were normally distributed. The power calculation was based on a study of Yoshioka, Doucet, Drapeau, Dionne, and Tremblay (2001), in which they investigated the combined effects of red pepper and caffeine on ad libitum intake in eight Caucasian subjects. Subject sample size was calculated using a power calculation based on 100%Control conditions, where negative energy balance was 20.5 ± 1.3%, respectively (Janssens et al., 2013). No significant differences were shown between men and women concerning appetite profile, ad libitum intake, overconsumption and overcompensation.

Results

Subject characteristics

Nineteen healthy subjects (9 males, 10 females) started the experiments; four subjects dropped out due to agenda problems. Fifteen subjects (7 females and 8 males) completed the four conditions. They had a mean age of 29.7 ± 10.8 years and a mean BMI of 23.3 ± 2.9 kg/m². Energy balance during 36 hours in the 100%CAPS and the 100%Control conditions were 0.15 ± 0.2 MJ/d and 0.22 ± 0.2 MJ/d, respectively, and did not significantly differ from 0. During the 75%CAPS and 75%Control conditions, negative energy balance was 20.5 ± 1.4%, and 19.2 ± 1.3%, respectively (Janssens et al., 2013). No significant differences were shown between men and women concerning appetite profile, ad libitum intake, overconsumption and overcompensation.

Appetite profile

Baseline ratings for appetite profile were not different between the four conditions. The appetite profile (Table 2) shows that the general satiety (P < 0.05) and fullness (P = 0.01, Fig. 1) over 36 hours, expressed as AUC, were significantly higher in the 100%CAPS condition compared with the 100%Control condition.

After dinner on day 1, desire to eat scores after 75%CAPS (26.6 ± 7.7 mm) did not differ from 100%Control (21.1 ± 5.2 mm), while desire to eat after 75%Control (35.2 ± 7.0 mm) was significantly higher than after 100%Control (21.1 ± 5.2 mm, P < 0.05). Similar observations were present with satiety and fullness. Satiety and fullness were not different for 75%CAPS versus 100%Control (satiety: 75%CAPS 69.5 ± 5.4 mm, 100%Control 77.8 ± 3.7 mm; fullness: 75%CAPS 67.7 ± 5.6 mm, 100%Control 75.0 ± 3.5 mm), while there was a trend toward lower feelings of satiety and fullness in 75%Control than in 100%Control (satiety: 75%Control 64.7 ± 5.6 mm, 100%Control 77.8 ± 3.7 mm (P = 0.06), fullness: 75%Control 58.9 ± 6.9 mm, 100%Control 75.0 ± 3.5 mm (P = 0.06)).

Pleasantness of taste, pungency, spiciness and heat sensation

Mean pleasantness of taste ratings of the test meals were 58.3 ± 10.4 mm for the 100%CAPS condition, 63.0 ± 6.2 mm for the 100%Control condition, 50.7 ± 12.7 mm for the 75%CAPS condition, and 60.3 ± 7.2 mm for the 75%Control condition. Pleasantness of taste of the test meals did not significantly differ between 100%Control and 100%CAPS nor between 100%Control and 75%Control. However, pleasantness of taste was significantly lower after 75%CAPS than after 75%Control (P = 0.01), and significantly
higher after 100%Control than after 75%CAPS ($P < 0.01$). Mean ratings concerning spiciness of the meals were 67.9 ± 3.1 mm for the 100%CAPS condition and 64.8 ± 4.0 mm for the 75%CAPS condition; these scores represent a very spicy solution, but not too spicy (Westerterp-Plantenga et al., 2005). Mean pungeency ratings were 65.7 ± 5.9 mm for the 100%CAPS condition, 6.8 ± 2.0 mm for the 100%Control condition, 65.3 ± 4.7 mm for the 75%CAPS condition and 8.7 ± 2.0 mm for the 75%Control condition ($P < 0.001$). Subjects also rated whether they got a heat sensation from eating the test meals; the mean ratings concerning the heat sensation of the meals were 41.3 ± 2.7 mm for the 100%CAPS condition, 9.9 ± 3.0 mm for the 100%Control condition, 35.0 ± 4.6 mm for the 75%CAPS condition and 13.8 ± 4.5 mm for the 75%Control condition ($P < 0.001$). Water intake did not differ between conditions.

**Ad libitum meal**

**Ad libitum intake**

There was a trend toward a decrease in ad libitum intake in the 100%CAPS condition compared with the 100%Control condition (Fig. 2); subjects ate 30% less of the ad libitum dinner in the 100%CAPS condition compared with the 100%Control condition ($P = 0.07$). They consumed 1.4 ± 0.4 MJ in the 100%CAPS condition and 2.0 ± 0.4 MJ in the 100% Control condition. However, this trend toward a decrease in ad libitum intake after addition of CAPS to the diet was not seen when subjects were fed in negative energy balance (75%CAPS, 2.4 ± 0.4 MJ and 75%Control 2.5 ± 0.3 MJ).

Furthermore, ad libitum intake was not significantly different between 100%Control and 75%CAPS nor between 100%Control and 75%Control.

**Overconsumption and overcompensation**

There was a trend toward decreased overconsumption after addition of CAPS to the diet in the 100% conditions ($P = 0.06$) (Table 3a). Overcompensation (Table 3b) was not significantly different between 75%CAPS and 75%Control.

**Discussion**

In the present study we investigated the 36 hour effects of 2.56 mg CAPS (1.03 g of red chili pepper, 39,050 SHU) with every meal on appetite profile and ad libitum energy intake in Caucasians, in energy balance as well as in negative energy balance. We showed that CAPS increased feelings of satiety and fullness in energy balance. Furthermore, there was a trend toward a decrease in ad libitum intake after addition of CAPS to the diet in the 100% conditions. After dinner, the effects of CAPS versus Control in 25% negative energy balance prevented the effects of the negative energy balance on appetite profile compared with 100% energy intake without CAPS.

The present study supports the reported enhancing anorexigenic sensations of CAPS in energy balance. However, CAPS did not affect feelings of satiety and fullness in negative energy balance. Two previous studies investigated the effects of CAPS on appetite profile in negative energy balance (Reinbach et al., 2009; Smeets et al., 2013). Reinbach et al. (2009) investigated the effects of a one-day exposure to CAPS on appetite and energy intake during negative energy balance. They reported that CAPS relatively increased satiety and fullness during negative energy balance. Furthermore, they found that a combination of CAPS and green tea suppressed hunger and increased satiety more during negative than during positive energy balance. This study lasted for three weeks, which obviously was necessary to establish this condition. An important difference between the current study and the study of Reinbach et al. (2009) is that we tested the effect of CAPS in energy balance and in negative energy balance, confirmed by measuring the difference between energy intake and energy expenditure. Furthermore, in a previous study, we investigated whether an 80% energy requirement diet of protein partly replacing carbohydrate, plus addition of CAPS, reached the same level of fullness ratings as a 100% of the energy requirement diet without high protein content, and without addition of CAPS. We did observe an increase in feelings of fullness with addition of CAPS to a diet with high protein content and we also found an increase in fullness when CAPS was added to a diet with normal protein content (Smeets et al., 2013). Furthermore, in the present study, we found a small but surprising effect of CAPS on desire to eat and a

![Fig. 2. Ad libitum intake for the 100%CAPS, 100%Control, 75%CAPS and 75%Control conditions in 15 subjects (seven women and eight men). Values are means, with standard errors represented by vertical bars. There was a trend towards a decrease in ad libitum intake in the 100%CAPS condition compared with the 100%Control condition ($P = 0.07$).](image-url)

**Table 3**

Overconsumption and overcompensation ($n = 15$).

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<thead>
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<tbody>
<tr>
<td>a: Overconsumption</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100%CAPS</td>
<td>3.35 ± 0.1</td>
<td>4.76 ± 0.5</td>
<td>39.6 ± 9.4</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>100%Control</td>
<td>3.35 ± 0.1</td>
<td>5.30 ± 0.5</td>
<td>55.3 ± 10.6</td>
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<td>b: Overcompensation</td>
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<td>75%CAPS</td>
<td>2.51 ± 0.1</td>
<td>4.96 ± 0.5</td>
<td>1.61 ± 0.4</td>
<td>46.4 ± 12.2</td>
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<tr>
<td>75%Control</td>
<td>2.51 ± 0.1</td>
<td>4.57 ± 0.4</td>
<td>1.62 ± 0.3</td>
<td>46.8 ± 7.8</td>
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Values are means with their standard errors (SE), $n = 15$.

* Ad libitum intake expressed as % of 100% of daily energy requirement.
trend toward significance on feelings of satiety and fullness in negative energy balance. The effect had to be built up during the day, and was not acutely present after breakfast or lunch. The observation on VAS after dinner underscores our hypothesis that CAPS in 25% negative energy balance prevents the effect of the negative energy balance compared with 100% energy intake without CAPS.

In line with a previous study on the effect of CAPS on ad libitum intake (Ludy & Mattes, 2011), we observed a trend toward a decrease in ad libitum intake after addition of CAPS. However, this decrease was not seen when subjects were fed in negative energy balance. These results on the effect of CAPS on ad libitum intake in negative energy balance are consistent with the findings of the study by Reinbach et al. (2009) with capsiate. Yet, capsiate was found to decrease the energy intake during positive energy balance. The present results of CAPS on ad libitum intake in energy balance showed that CAPS might contribute to prevention of overeating. We found a trend toward a decrease in ad libitum intake when CAPS was added to meals with a normal fat content of 30 En%. This implies that the effect of CAPS on energy intake depends on the macronutrient composition of the meals: this beneficial effect of CAPS mainly has been to meals with a normal fat content of 30 En%. This implies that the addition of CAPS to the meals that were served in energy balance did not decrease the pleasantness of taste of the meals; therefore, it is not possible that the increased feelings of satiety and fullness and the trend toward decreased ad libitum intake in the 100%CAPS condition were due to the pleasantness of taste of the meals. The higher fullness and satiety observed with CAPS in energy balance might be supported by the higher pungency observed.

Strengths of this study are the fully controlled design, measurements in energy balance as well as in negative energy balance, and knowing the magnitude of the negative energy balance. In summary, the effects of CAPS are dependent on the dosage of CAPS given, energy intake, macronutrient composition of the meals and the maximum tolerable dose of the subjects.

Taken together, the present study shows that in energy balance, addition of 1.03 g of red chili pepper to meals with a normal fat and normal protein content increases satiety and fullness, and tends to prevent overeating in Caucasians. After dinner, capsiacin prevents the effects of the negative energy balance on desire to eat.

References