Addition of Capsaicin and Exchange of Carbohydrate with Protein Counteract Energy Intake Restriction Effects on Fullness and Energy Expenditure

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Abstract

Energy intake restriction causes a yo-yo effect by decreasing energy expenditure (EE) and decreasing fullness. We investigated the 24-h effect of protein and capsaicin, singly or combined, on fullness and EE during 20% energy intake restriction. The 24 participants (12 male, 12 female; BMI, 25.2 ± 0.4 kg/m²; age, 27 ± 4 y; body fat, 25.6 ± 5.7%; 3-factor eating questionnaire, F1: 6 ± 2, F2: 4 ± 2, F3: 3 ± 2) underwent eight 36-h sessions in a respiration chamber. The study had a randomized crossover design with 8 randomly sequenced conditions. The participants were fed 100 or 80% of their daily energy requirements. There were 2 control (C) conditions: 100%C and 80%C; 2 conditions with capsaicin (Caps): 100%Caps and 80%Caps; 2 conditions with elevated protein (P): 100%P and 80%P; and 2 conditions with a mixture of protein and capsaicin (PCaps): 100%PCaps and 80%PCaps. Appetite profile, EE, and substrate oxidation were monitored. Compared with 100%C, the 80%C group had expected negative energy-balance effects with respect to total EE, diet-induced thermogenesis, and fullness, whereas the 80%Caps diet counteracted these effects, and the 80%P and 80%PCaps diets exceeded these effects (P < 0.01). In energy balance and negative energy balance, fat balance was more negative in the 80%Caps, P, and PCaps groups than in the 80%C group (P < 0.05) and respiratory quotient values were lower. A negative protein balance was prevented with the 80%P and 80%PCaps diets compared with the 80%C diet. Our results suggest that protein and capsaicin, consumed singly or mixed, counteracted the energy intake restriction effects on fullness and EE. During energy restriction, protein and capsaicin promoted a negative fat balance and protein treatments also prevented a negative protein balance.

Introduction

Obesity is associated with an increased risk for chronic diseases, including type 2 diabetes, cancer, and cardiovascular disease (1). Modest weight loss (5–10% of body weight) is associated with clinical improvements, such as decreased risk for diabetes (2) and reductions in dyslipidemia and hypertension (3). Under normal circumstances, body weight is very tightly regulated. After a period of energy intake restriction and weight loss, the body responds with several mechanisms such as increasing hunger and decreasing energy expenditure (EE) to regain its initial body weight (4). These counteractive mechanisms make adherence to weight-loss diets difficult and uncomfortable. Therefore, it is important to test concepts that tackle the undesirable physiological responses of the body to body weight loss. In that perspective, several food components have been studied for their effect on appetite-related feelings and thermogenesis. High-protein foods are known to have a higher thermogenic effect and to be more satiating than normal-protein foods over the short as well as long term (5–7).

The protein-induced satiety may be due to elevated (especially ketogenic) plasma amino acid concentrations, diet-induced thermogenesis (DIT), hunger suppression, and possibly increased anorexic hormone concentrations (8). The protein-induced EE may be due to protein-related, high DIT of 20–30% due to protein turnover, urea production, and gluconeogenesis (8). Moreover, a protein diet stimulates fat oxidation (5,6,8), partly due to the higher EE leading to faster glycogen depletion, especially overnight, and thus greater fat oxidation. Then mRNA levels of genes involved in carbohydrate and lipid metabolism in the liver are affected. In liver, a protein diet decreases mRNA encoding glycolysis enzymes (glucokinase, L-pyruvate kinase) and lipogenesis
enzymes (acetyl-CoA carboxylase, fatty acid synthase); increases RNA encoding gluconeogenesis enzymes (phosphoenolpyruvate carboxykinase); first lowers, then restores RNA encoding glyco-
gen synthesis enzyme (glycogen synthase); and does not change RNA encoding β-oxidation enzymes (carnitine palmitoyltransferase 1, peroxisomal acyl-coenzyme A oxidase 1, β hydroxyacyl CoA dehydrogenase) (9). Following a protein diet, carbohydrate oxidation is increased beyond carbohydrate intake, resulting in a negative carbohydrate balance, while lipogenesis is decreased, explaining the negative fat balance in protein diets (5,6,8,9).

Capsaicin, the pungent ingredient of red pepper, has been reported to increase EE and DIT, probably due to β-adrenergic stimulation and a decrease in the respiratory quotient (RQ), implying a shift in substrate oxidation from carbohydrate to fat oxidation (10–13). The addition of capsaicin to a diet has also been shown to increase satiety and decrease appetite and cumulative food intake (13–15). Whether during weight loss, in negative energy balance, reductions in EE and feelings of fullness can be prevented by consuming protein and capsaicin remains to be shown. Therefore, the aim of the present study was to investigate whether an 80% energy requirement diet consisting of partly replacing carbohydrate by protein plus the addition of capsaicin reaches the same level of fullness ratings and EE as a 100% energy requirement control diet. To proof this concept, studies in participants in energy balance (100%) as well in negative energy balance (80%) who consumed control (C) diets (100%C and 80% C), C diets with added capsaicin (100%Caps and 80%Caps), diets with carbohydrate replaced in part by protein (100%P and 80% P), and diets with added capsaicin and carbohydrate replaced in part by protein (100%PCaps and 80%PCaps) were performed for 2 d in a fully energy balance-controlled condition in the respiratory chamber.

Subjects and Methods

Subjects. Twenty-eight healthy participants were recruited by adver-
tisements in the local newspapers and on notice boards at the university. Participants were selected based on age, height, weight, and BMI. The power calculation was based on values of hunger and EE and its components from studies by Hochstenbein-Waelen et al. (16,17), Lejeune et al. (14), and Westerterp-Plantenga et al. (18). Eating behavior was assessed using a validated Dutch translation of the Three Factor Eating Questionnaire (TFEQ) (19). Cognitive restrained and unrestrained eating behavior [factor 1 (F1)], emotional eating and disinhibition [factor 2 (F2)], and the subjective feeling of hunger [factor 3 (F3)] were scored. Cognitive restraint (F1) implies full control over the amount and type of food intake; disinhibition (F2) implies inhibition of cognitive restraint as well as emotional eating; the factor hunger implies a continuous feeling of hunger (F3) (19). Individuals were excluded from participation if their F1 score on the TFEQ was ≤9. Participants’ mean scores on the TFEQ were: F1, 6 ± 2; F2, 4 ± 2; and F3, 3 ± 2, indicating low levels of cognitive restraint, disinhibition, and general hunger. Selected participants were healthy, not taking medication, nonsmoking, and not dieting; they gave written informed consent and the study was approved by the Medical Ethics Committee of Maastricht University. The study was conducted in the metabolic unit of Maastricht University Department of Human Biology.

Study protocol. To test the hypothesis that feeding the participants 80% of their individual energy requirement with the addition of capsaicin and partly and iso-energetically replacing carbohydrate with protein would preserve EE and fullness, the following assumptions had to be confirmed: 1) achievement of negative energy balance as a result of feeding 80% of the energy requirement (80%C); 2) decreased fullness and decreased EE in the 80% energy requirement control condition (80% C); and 3) increased EE and fullness in energy balance with added capsaicin and partly and iso-energetically replacing carbohydrate with protein (100%PCaps) as well as with only capsaicin (100%Caps) and only carbohydrate replacement with protein (100%P).

The 8 conditions (100%C, 80%C, 100%Caps, 80%Caps, 100%P, 80%P, 100%PCaps, and 80%PCaps) had a single-blind, randomized, crossover design. The respiratory chamber sessions were conducted 4 wk apart in women to ensure that each female participant was in the same phase of her menstrual cycle. In men, the sessions were conducted at least 7 d apart. Two days prior to each session, the participants were provided with a standardized diet to consume at home in order to be fed in energy balance and to receive the same macronutrient proportions as during the respiration chamber experiment. Moreover, caffeine intake was stan-
dardized at a maximum of 100 mg/d (1 cup of coffee or 3 cups of tea). Before the test was started, the participants were asked whether they had encountered any difficulties while consuming the diet at home.

For the respiratory chamber measurements, the participants entered the respiration chamber at 0800 h after an overnight fast. They were instructed to go to bed at ~2300 h. The next day, the participants followed the same protocol as the day before. At 0800 h on d 2, the participants were released from the respiration chamber.

Experimental diets. The energy content of the diet that the participants consumed at home was based on basal metabolic rate calculated with the equation of Harris-Benedict (20) and multiplied by an activity index of 1.7 (21). In the respiration chamber, energy requirements were calcu-
lated based on basal metabolic rate multiplied by an activity index of 1.4. The participants had to completely finish all drinks and meals. For the presentation of the control and treatment conditions for food and energy intake, see Table 1.

Appetite profile. Appetite profile (hunger, fullness, satiety, and desire to eat) was measured using anchored, 100-mm visual analogue scales. During each 36-h session, these questionnaires were completed every waking hour and before and after every meal. The scale is anchored from “not at all” on the left to “extremely” on the right. The visual analogue scale data are given as AUC, which is the area above the baseline calculated by the conventional trapezoidal rule.

Anthropometrics. Anthropometric measurements were performed at baseline. The participants were weighed in their underwear after an overnight fast by using a calibrated hospital scale to the nearest 0.1 kg (Tanita TBF–310). Height was measured at screening to the nearest 0.1 cm (Seca-stadiometer). Body composition was measured by using the deuterium dilution technique. 2H2O dilution was used to measure total body water (TBW). The participants were asked to collect a urine sample in the evening just before drinking the deuterium-enriched water solution. After ingestion of this solution, the participants went to bed and no additional consumption was allowed for this period. Ten hours after drinking the water solution, another urine sample was collected. The dilution of the deuterium isotope is a measure of the participant’s TBW. Deuterium was measured in the urine samples with an isotope ratio mass spectrometer (VG-bogas Aqua Sira; VG Isogas). TBW was obtained by dividing the measured deuterium dilution space by 1.04. Fat-free mass was calculated by dividing TBW by the hydration factor 0.73. Fat mass was measured as BW – fat-free mass (7,22,23).

Indirect calorimetry. Oxygen consumption and carbon dioxide production were measured in the respiration chamber (14,24). The respiration chamber is a 14-m3 room furnished with a bed, chair, computer, television, radio cassette player, telephone, intercom, sink, and toilet. The room was ventilated with fresh air at a rate of 70–80 L/ min. The ventilation rate was measured with a dry gas meter (type 4; Schleuniger). The concentrations of oxygen and carbon dioxide were measured with the use of an infrared carbon dioxide analyzer (Uras 3G; Hartmann and Braun) and 2 paramagnetic oxygen analyzers: Magnos 6G (Hartmann and Braun) and type OA184A (Servomex). During each 15-min period, 6 samples of outgoing air for each chamber, 1 sample over night fast by using a calibrated hospital scale to the nearest 0.1 kg (Tanita TBF–310). Height was measured at screening to the nearest 0.1 cm (Seca-stadiometer). Body composition was measured by using the deuterium dilution technique. 2H2O dilution was used to measure total body water (TBW). The participants were asked to collect a urine sample in the evening just before drinking the deuterium-enriched water solution. After ingestion of this solution, the participants went to bed and no additional consumption was allowed for this period. Ten hours after drinking the water solution, another urine sample was collected. The dilution of the deuterium isotope is a measure of the participant’s TBW. Deuterium was measured in the urine samples with an isotope ratio mass spectrometer (VG-bogas Aqua Sira; VG Isogas). TBW was obtained by dividing the measured deuterium dilution space by 1.04. Fat-free mass was calculated by dividing TBW by the hydration factor 0.73. Fat mass was measured as BW – fat-free mass (7,22,23).

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EE and substrate oxidation. Twenty-four-hour EE, as measured in the respiratory chamber, consists of sleeping metabolic rate (SMR), DIT, and activity-induced EE (AEE). Activity was monitored with a radar system based on the Doppler principle. SMR was defined as the lowest mean EE measured for 3 consecutive h between 0000 and 0700 h. Resting EE (REE) was calculated by plotting EE against the radar output; both were averaged for 30-min periods. The intercept of the regression line at the lowest radar output represents the EE in the inactive state REE, which consists of SMR and DIT (24). DIT was determined by subtracting SMR from REE. AEE was determined by subtracting SMR and DIT from 24-h EE. Carbohydrate, fat, and protein oxidation were calculated from the measurements of oxygen consumption, carbon dioxide production, and urinary nitrogen excretion by using the formula of Carpenter in Brouwer and F. Repeated-measures ANOVA with gender as covariate was used to determine possible differences between male and female participants. All statistical tests are 2-sided and differences were considered significant if $P < 0.05$. Data are presented as mean ± SD unless otherwise indicated.

Results
Twenty-four healthy participants (12 males and 12 females) completed the 8 conditions. The participants had a mean age of 27 ± 4 y, BMI of 25.2 ± 0.4 kg/m$^2$, and body fat of 25.6 ± 5.7%. Participants’ mean scores on the TFEQ were: F1, 6 ± 2; F2, 4 ± 2; and F3, 3 ± 2, indicating low levels of cognitive restraint, disinhibition, and general hunger. No adverse events occurred. For the results, no differences from the interventions between men and women appeared; therefore, the results were taken together (Table 2).

Respiratory chamber experiments. Energy balance was achieved in the 100%C condition. In the 100% condition with P or PCaps, energy balance was slightly but significantly negative due to the elevated total EE (TEE), whereas the energy intake did not differ. In the 80%C condition, negative energy balance was achieved. When the participants consumed 80% of their individual energy requirements, the negative energy balance was $-1.6 ± 0.2$ MJ due to the reduced energy intake minus the significant EE reductions in SMR and DIT, adapting to the reduced energy intake. In the 80% condition with Caps, P, and PCaps, negative energy balance was significantly more negative than in the 80%C condition due to a higher SMR and DIT, resulting in a higher TEE than in the 80%C condition (Table 2). The following comparisons are relevant (Table 2). When the participants were fed in energy balance, TEE in the Caps (P < 0.05), P (P < 0.01), and PCaps (P < 0.01) groups was higher than that in the 100%C group. In the 80% energy intake participants, TEE was higher in the Caps (P < 0.05), P (P < 0.05), and PCaps (P < 0.01) groups than that in the 80%C group. At 80% energy intake, TEE in the 80%Caps group did not differ significantly from that in the 100%C group, whereas TEE was, as expected, lower in the 80%C group. In the 80%P (P < 0.05) and 80%PCaps (P < 0.05) groups, TEE was lower than in the 100%C group. TEE was, as expected, lower in the 80%Caps group than in the 100%Caps group, in the 80%P compared with the 100%P group, and in the 80%PCaps compared with the 100%PCaps (P < 0.01) group.

Elevated TEE in the Caps, P, or PCaps groups consisted of elevated DIT, whereas the SMR and AEE did not differ. Lower TEE in the 80%C than in the 100%C group consisted of lower DIT and sometimes lower SMR, whereas the AEE did not differ. Reduced TEE in the 80%Caps compared with 100% Caps, 80%P compared with 100%P, and 80%PCaps compared with 100%PCaps groups consisted of reduced DIT, whereas SMR and AEE remained the same (Table 2).

Substrate oxidation. The RQ was lower and the fat balance was more negative in the 100%Caps (P < 0.05), P, and PCaps (P < 0.01) groups than in the 100%C group.

Similarly, the RQ was lower and the fat balance was more negative in the 80%Caps (P < 0.05), P (P < 0.05), and PCaps (P < 0.01) groups than in the 80%C group. In the P and PCaps groups, protein balances were more positive than in the similar 80% or 100% C or Caps groups (Table 2).

Fullness. Because the ratings of fullness and feelings of satiety were similar and because these ratings were opposite to the ratings of hunger and desire to eat, only the ratings of fullness are shown. Comparing the AUC for 24 h of fullness with the C conditions, it appeared that fullness was higher in the 100%Caps (P < 0.05), 100%P (P < 0.01), and 100%PCaps (P < 0.01) groups.
than in the 100%C group. Also, fullness was greater in the 80%C Caps (P < 0.05), 80%P (P < 0.01), and 80%PCaps (P < 0.01) groups than in the 80%C group and was greater in the 80% and 80%PCaps groups than in the 100%C (P < 0.05) group, whereas it was lower in the 80%C group compared with the 100%C group (P < 0.01) (Table 2).

**TABLE 2**  TEE, components of EE, EI, RQ, substrate oxidation, and fullness scores in the 8 conditions

<table>
<thead>
<tr>
<th></th>
<th>100%C</th>
<th>80%C</th>
<th>100%Caps</th>
<th>80%Caps</th>
<th>100%P</th>
<th>80%P</th>
<th>100%PCaps</th>
<th>80%PCaps</th>
</tr>
</thead>
<tbody>
<tr>
<td>TEE, MJ/d</td>
<td>10.1 ± 0.2a</td>
<td>9.6 ± 0.2b</td>
<td>10.3 ± 0.2c</td>
<td>10.0 ± 0.2c</td>
<td>10.4 ± 0.2c</td>
<td>10.2 ± 0.2c</td>
<td>10.6 ± 0.2c</td>
<td>10.3 ± 0.2c</td>
</tr>
<tr>
<td>TEE, % of 100%C</td>
<td>100</td>
<td>100</td>
<td>102</td>
<td>100</td>
<td>103</td>
<td>101</td>
<td>105</td>
<td>102</td>
</tr>
<tr>
<td>SMR, MJ/d</td>
<td>7.2 ± 0.2a</td>
<td>6.9 ± 0.2b</td>
<td>7.1 ± 0.2c</td>
<td>7.1 ± 0.2c</td>
<td>7.1 ± 0.2c</td>
<td>7.1 ± 0.2c</td>
<td>7.1 ± 0.2c</td>
<td>7.1 ± 0.2c</td>
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<tr>
<td>DIT, MJ/d</td>
<td>1.0 ± 0.1a</td>
<td>0.8 ± 0.1b</td>
<td>1.3 ± 0.1c</td>
<td>1.0 ± 0.1c</td>
<td>1.4 ± 0.1d</td>
<td>1.2 ± 0.1e</td>
<td>1.6 ± 0.1f</td>
<td>1.3 ± 0.1g</td>
</tr>
<tr>
<td>DIT, % of EI</td>
<td>9.1</td>
<td>9.0</td>
<td>10.0</td>
<td>12.9</td>
<td>12.5</td>
<td>14.9</td>
<td>15.0</td>
<td>15.8</td>
</tr>
<tr>
<td>AEE, MJ/d</td>
<td>1.9 ± 0.1</td>
<td>1.9 ± 0.1</td>
<td>1.9 ± 0.1</td>
<td>1.9 ± 0.1</td>
<td>1.9 ± 0.1</td>
<td>1.9 ± 0.1</td>
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<tr>
<td>EL, MJ/d</td>
<td>10.1 ± 0.4a</td>
<td>8.0 ± 0.4b</td>
<td>10.1 ± 0.4c</td>
<td>10.1 ± 0.4c</td>
<td>10.1 ± 0.4d</td>
<td>8.0 ± 0.4e</td>
<td>10.1 ± 0.4f</td>
<td>8.0 ± 0.4g</td>
</tr>
<tr>
<td>EB, MJ/d</td>
<td>0.0 ± 0.2a</td>
<td>0.2 ± 0.2b</td>
<td>0.2 ± 0.2c</td>
<td>0.2 ± 0.2c</td>
<td>0.3 ± 0.2c</td>
<td>0.2 ± 0.2c</td>
<td>0.5 ± 0.2c</td>
<td>0.2 ± 0.2c</td>
</tr>
<tr>
<td>EB, % of 100% EB</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
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<tr>
<td>Ro2, MJ/d</td>
<td>0.89 ± 0.01a</td>
<td>0.97 ± 0.01b</td>
<td>0.88 ± 0.01c</td>
<td>0.86 ± 0.01c</td>
<td>0.87 ± 0.01d</td>
<td>0.86 ± 0.01e</td>
<td>0.86 ± 0.01f</td>
<td>0.85 ± 0.01g</td>
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<tr>
<td>Ro, % of 100%C</td>
<td>100</td>
<td>100</td>
<td>100</td>
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<td>100</td>
<td>100</td>
<td>100</td>
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<tr>
<td>Fat balance, g/d</td>
<td>2 ± 1a</td>
<td>14 ± 6a</td>
<td>10 ± 6a</td>
<td>10 ± 6a</td>
<td>10 ± 6a</td>
<td>20 ± 6a</td>
<td>12 ± 6a</td>
<td>22 ± 6a</td>
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<tr>
<td>Carbohydrate balance, g/d</td>
<td>0 ± 1a</td>
<td>8 ± 6a</td>
<td>6 ± 6a</td>
<td>6 ± 6a</td>
<td>6 ± 6a</td>
<td>12 ± 6a</td>
<td>14 ± 6a</td>
<td>15 ± 6a</td>
</tr>
<tr>
<td>Protein balance, g/d</td>
<td>0 ± 1a</td>
<td>0 ± 1a</td>
<td>0 ± 1a</td>
<td>0 ± 1a</td>
<td>0 ± 1a</td>
<td>0 ± 1a</td>
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<tr>
<td>Fullness scores,2 AUC</td>
<td>1440 ± 98a</td>
<td>1224 ± 112b</td>
<td>1584 ± 102c</td>
<td>1421 ± 112b</td>
<td>1721 ± 147d</td>
<td>1593 ± 121e</td>
<td>1839 ± 132c</td>
<td>1664 ± 118d</td>
</tr>
<tr>
<td>Fullness, % of 100%C</td>
<td>100</td>
<td>85</td>
<td>110</td>
<td>99</td>
<td>120</td>
<td>110</td>
<td>128</td>
<td>115</td>
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</table>

1 Values are mean ± SEM, n = 24. Data were analyzed using repeated-measures ANOVA. Means in a row without a common letter differ, P < 0.05. AEE, activity-induced energy expenditure; DIT, diet-induced thermogenesis; EE, energy balance; EI, energy expenditure; EI, energy intake; RQ, respiratory quotient; SMR, sleeping metabolic rate; TEE, total energy expenditure. In the following conditions: 100%C and 80%C (percent energy from carbohydrate/protein/fat: 60/10/30); P and PCaps: (percent energy from carbohydrate/protein/fat: 40/20/40); capsaicin: 1030 mg red pepper/meal; Caps: C plus 1030 mg red pepper/meal. Magnitudes of differences are expressed as percent. 2 Overall effects among the 8 conditions, P < 0.001.

**Discussion**

In the present study, the central question was whether in negative energy balance, the original level of EE and fullness as in neutral balance, is preserved, when capsaicin is added to the diet and carbohydrate is partly replaced by protein. To test the hypothesis that feeding the participants 80% of their individual energy requirement with the addition of capsaicin and with partly and iso-energetically replacing carbohydrate with protein would preserve EE and fullness, the following assumptions were made and had to be confirmed: 1) achievement of negative energy balance as a result of feeding 80% of energy requirement (80%C); 2) decreased fullness and EE in the 80% energy requirement control condition (80%C); and 3) increased EE and fullness in energy balance with added capsaicin and partly and iso-energetically replacing carbohydrate with protein (100% PCaps), with only the capsaicin addition (100%C Caps), and with only carbohydrate replacement with protein (100% P). All assumptions were confirmed in line with previous studies, which assessed the administration of these ingredients individually (5,6,10–15,18,26–37) as well as in combination (38,39). The short-term controlled studies assessed these ingredients mainly in energy balance (6,9–12,14–17,26,28,30,33,37), whereas longer term studies assessed these effects in negative energy balance (5,13,27,29,34–36). The present study shows the effects of these ingredients measured for 24 h under controlled energy and negative energy balance conditions.

Negative energy balance was achieved by feeding the participants 80% of their energy requirements. It then appeared that the 20% underfeeding did not result in a 20% negative energy balance, yet, due to physiological adaptation of DIT and SMR, it resulted in a 16% negative energy balance in the control group. In the Caps, P, and PCaps groups, it resulted in a 20–23% negative energy balance, because a possible reduction in SMR was prevented and DIT increased compared with the 100%C group, resulting in a similar TEE with the Caps group and an increase in TEE in the P and PCaps groups. With respect to EE, the key components that prevent TEE from decreasing in negative energy balance or even increasing are DIT and SMR. The observation that in energy balance DIT increases upon the addition of capsaicin or the exchange of carbohydrate with protein was previously shown (10–13,30,33); a relative increase in SMR in energy balance has also been shown before (6,15,16). We speculated that the acute increase in DIT (30) might over a few days develop in an increase in SMR (13,15,16), and DIT even may even rebound (15,16). This increase in SMR may be an adaptation of the body to a high-protein diet with respect to an enhanced protein turnover and a positive nitrogen balance. Enhanced protein turnover with a higher protein-diet has been observed in rats, but it has not yet been confirmed in humans (31). Moreover, in the 80%C group, fullness decreased by 15%, whereas in the 80% Caps group, fullness did not differ from the 100%C group, and in the 80% with P and PCaps treatments, fullness increased 10–15% compared with the 100%C group.

Answering the main question not only revealed that addition of capsaicin and application of partly iso-energetically carbohydrate replaced by protein would prevent the usual reduction in fullness and EE, but in the conditions that exchanged carbohydrate with protein, it even exceeded it. Obviously, the magnitudes of the differences were so powerful that a surplus occurred. These data suggest that reducing the effects of energy restriction on EE may be prevented or reversed by capsaicin, protein, and capsaicin plus protein. Replacing carbohydrate with protein shows the largest effect. The effects of this treatment did not significantly differ from the same treatment with capsaicin added to it. Adding capsaicin only tended to increase the effect (0.05 < P ≤ 0.10). Nevertheless, it was shown that capsaicin was able to counteract 20% energy intake reduction effects, namely EE and fullness.
Administration of protein and of protein plus capsaicin during energy restriction in the present study resulted furthermore in lowering the fat balance and preserving the protein balance. The exchange of 15% of total energy intake from carbohydrate to protein and the addition of capsaicin given during energy restriction prevented the 24-h protein balance from becoming negative. None of the observed effects was influenced by differences in activity, as the AEE did not differ between the 4 conditions. Furthermore, the capsaicin alone, protein alone, and protein plus capsaicin treatments were well tolerated by all participants. We observed an immediate negative effect on TEE of energy restriction when comparing TEE in the 80%C group with that in the 100%C group. This decline in TEE due to energy restriction was, however, completely abolished with capsaicin alone and even overcompensated with protein and protein plus capsaicin. Here, we report the effects during a 2-d period. We do not know whether the observed effects persist over time or whether compensatory mechanisms will be triggered. In a previous weight-loss study, the additional thermogenic effect of a bioactive supplement was sustained for 8 wk, which suggests that stimulating effects of bioactive components on EE do not diminish over time (38). The results are in agreement with previous studies comparing administration of these ingredients individually (5,6,10–15,18,26–37) and in combination (38,39). Despite the main limitation of the study, which was that it was conducted over a relatively short period of time, the results are in line with those from previous studies, which showed that an adaptation of 2 d before to the macronutrient composition offered is sufficient (6,37). Although participants were not adapted to 20% energy restriction nor to receive the additional capsaicin before the corresponding test periods, it is unlikely that the effects that were obtained would be only transient. Previous studies reported that both capsaicin addition (13) and a carbohydrate-protein exchange (5) during 3 mo of negative energy balance still had a higher satiety compared with baseline and prevented a decrease in REE (5,13). In those studies, due to the weight loss, the increased EE, as was shown in the present study, was at least sustained as a prevention of the usual decrease (5,13). The novelty of this study is the comparison of the single as well as the combined treatments and the comparisons of the magnitudes of the effects. Moreover, the study proposes to follow the paradigm of introducing a negative energy balance and offer ingredients to be able to support this, instead of offering ingredients and waiting until a negative energy balance would spontaneously occur. Furthermore, the study shows that when the magnitudes of effects of ingredients on TEE, in neutral energy balance are ~2–5%, counterbalancing in negative energy balance may be expected. With respect to the appetite profile, when the effects on fullness and related questions are 10–30% in energy balance, an effect in negative energy balance is still likely to occur.

In summary, a combination of the addition of capsaicin and carbohydrate replacement by protein with a 20% energy-restricted diet, or carbohydrate/protein exchange alone resulted in higher EE and fullness compared with a control diet in energy balance. Fat balance was more negative in the capsaicin addition plus carbohydrate/protein exchange compared with a control energy-restricted diet. Therefore, a combination of protein and capsaicin, or capsaicin or protein alone, may at least maintain normal levels of EE and fullness during energy restriction. The effectiveness of the capsaicin and protein should be further evaluated in well-designed weight-loss studies in overweight and obese individuals.

Acknowledgments
The authors gratefully thank Karianna Theunissen-Beekman and Freeha Faizi for their assistance and Øydis Ueland and Andras Salgo for providing us with their products. A.J.S. and P.L.H.R.J. designed the experiment, collected the data, analyzed the data, and wrote the manuscript; M.S.W.-P. designed the experiment, helped analyze the data, wrote the manuscript, and supervised the project. All authors read and approved the final manuscript.

Literature Cited

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