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PAPER

Sensory and gastrointestinal satiety effects of capsaicin on food intake

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BACKGROUND: Decreased appetite and increased energy expenditure after oral consumption of red pepper has been shown.
OBJECTIVE: The aim of the present study was to assess the relative oral and gastrointestinal contribution to capsaicin-induced satiety and its effects on food intake or macronutrient selection.
METHODS: For 24 subjects (12 men and 12 women; age: 35 ± 10 y; BMI: 25.0 ± 2.4 kg/m^2; range 20–30), 16 h food intake was assessed four times during 2 consecutive days by offering macronutrient-specific buffets and boxes with snacks, in our laboratory restaurant. At 30 min before each meal, 0.9 g red pepper (0.25% capsaicin; 80 000 Scoville Thermal Units) or a placebo was offered in either tomato juice or in two capsules that were swallowed with tomato juice. Hunger and satiety were recorded using Visual Analogue Scales.
RESULTS: Average daily energy intake in the placebo condition was 11.5 ± 1.0 MJ/d for the men and 9.4 ± 0.8 MJ/d for the women. After capsaicin capsules, energy intake was 10.4 ± 0.6 and 8.3 ± 0.5 MJ/d ($P<0.01$); after capsaicin in tomato juice, it was 9.9 ± 0.7 and 7.9 ± 0.5 MJ/d, respectively (compared to placebo: $P<0.001$; compared to capsaicin in capsules: $P<0.05$). En % from carbohydrate/protein/fat (C/P/F): changed from $46\pm3/15\pm1/39\pm2$ to $52\pm4/15\pm1/33\pm2$ en% ($P<0.01$) in the men, and from $48\pm4/14\pm2/38\pm3$ to $42\pm4/14\pm2/32\pm3$ en% ($P<0.01$) in the women, in both capsaicin conditions. Satiety (area under the curve) increased from 689 to 757 mmh in the men and from 712 to 806 mmh in the women, both ($P<0.01$). Only in the oral exposure condition was the reduction in energy intake and the increase in satiety related to perceived spiciness.
CONCLUSIONS: In the short term, both oral and gastrointestinal exposure to capsaicin increased satiety and reduced energy and fat intake; the stronger reduction with oral exposure suggests a sensory effect of capsaicin.
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Keywords: energy intake; sensory satiety; postingestive satiety; macronutrients composition; cephalic phase response

Introduction

The increasing incidence of obesity is a recognized medical problem in developed countries.[1] Obesity is a major factor for a number of comorbidities such as coronary heart diseases, hypertension, noninsulin-dependent diabetes mellitus, pulmonary dysfunction, osteoarthritis and certain types of cancer.[2–4]

The main factor causing the development of obesity is a positive energy balance through a decreased physical activity and increased energy intake, especially fat intake. Weight loss and loss of body fat can thus be achieved by reducing energy intake and/or increasing energy expenditure.

Treatment of obesity is beneficial in that even modest weight loss reduces the risk for mortality and morbidity in obese subjects and leads to beneficial health effects.[5–7] Modest weight loss is a realistic goal for most subjects[5,7] and can be achieved by reducing energy intake. However, weight-maintenance after weight loss has rarely been shown, and weight regain usually occurs,[8–12] indicating that subjects are not able to change their eating and activity behavior adequately.[13] Interventions aimed to improve weight loss and weight maintenance and to prevent the development of obesity in already overweight subjects are therefore necessary. A rapidly growing therapeutic area, largely embraced by the general public, is the use of natural herbal supplements. One of these agents is capsaicin, the pungent principle of hot red pepper. Capsaicin has been reported to reduce adiposity in rats, which can be partly explained by the enhancing effects on energy and lipid metabolism via catecholamine secretion from the adrenal medulla through sympathetic activation of the central nervous system.[14,15] In a series of

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human studies, Yoshioka *et al*[16–19] showed an increase in diet-induced thermogenesis and a decrease in respiratory quotient immediately after a meal to which red pepper (capsaicin) was added. This finding implies a shift in substrate oxidation from carbohydrate to fat oxidation. This increase in the facultative phase of diet-induced thermogenesis was probably due to beta-adrenergic stimulation.[16] They also showed a decreased appetite, decreased cumulative food intake[18] and increased energy expenditure[17,19] after consumption of red pepper. In those studies by Yoshioka, capsaicin was given orally as red pepper. Therefore, the reducing effect on energy intake could be due to the sensory effect of capsaicin or the postingestive, gastrointestinal effect. We assessed the sensory and gastrointestinal contributions to the possible satiety effect of capsaicin by offering the same dosage of capsaicin in tomato juice (sensory and gastrointestinal exposure) or in capsules (gastrointestinal exposure) that were swallowed with tomato juice.

Subjects and method

Subjects

In all, 30 male and female Caucasian subjects, aged 20 to 50 y, were recruited for this study. They underwent a medical screening. Body weight was measured on a digital balance (Seca, model 707, Hamburg Germany; weighing accuracy of 0.1 kg) with subjects in underwear, in a fasted state and after voiding their bladder. Height was measured using a wall-mounted stadiometer (Seca, model 220, Hamburg, Germany). Attitude towards food intake was determined using a Dutch translation of the Three Factor Eating Questionnaire (TFEQ).[20,21] The first factor of the TFEQ (F1) measures cognitive restrained eating: control of food intake by thought and will power. The second factor (F2) represents disinhibition: an incidental inability to resist eating cues, or inhibition of dietary restraint, and emotional eating.[20,21] The third factor (F3) examines the subjective feeling of general hunger.[20,21]

Selection resulted in 24 eligible subjects who were in good health, nonsmokers, not using medication, not under dietary restraint and at most moderate alcohol users. Moreover, they were used to eating spicy foods at least once a week.

The subjects comprising 12 men and 12 women were normal weight to moderately overweight and were of age: 35 ± 10 y; BMI: 25.0 ± 2.4 kg/m^2; range 20–30. Scores on the TFEQ factors: F1, 5 ± 2; F2, 6 ± 2; F3, 4 ± 2 indicated that the subjects were not dietary restraint (cutoff point in our population: F1 = 9), did not show a tendency to disinhibition and did not show a very high general feeling of hunger as indicated by F3.[13,21] All subjects gave their written informed consent. The Medical Ethics Committee of the Academic Hospital in Maastricht approved of the study.

Procedure

Subjects came to the laboratory on 2 consecutive days, four times, during 4 consecutive weeks. Every time they received macronutrient-specific buffet-style meals, and after every meal a fresh box of snacks for in between meals. Before each meal, the previous box of snacks with leftovers had to be delivered. The snacks were labeled 'not for children' to prevent the subjects from sharing them with others. Subjects were instructed not to eat or drink other items than those being offered during the experimental days, except plain water, black coffee or tea.

Breakfast and lunch consisted of a buffet with high- and low-fat food items, that is, high-fat: croissants with butter and cheese, croissants with butter and sausages, croissants with butter and 'light' jam, sausage rolls, chocolate rolls, full-fat milk, full-fat yoghurt, cream to be added to coffee; low-fat: rolls with low-fat margarine and low-fat cheese, low-fat margarine and smoked meat, low-fat margarine and jam, currant buns, sticky sugar buns, skimmed milk, low-fat yoghurt, sugar to be added to coffee, and coffee and water. Dinner consisted of a buffet with high- and low-fat food items, that is, high-fat salads, soups, mashed potatoes, baked potatoes, vegetables with high-fat sauces, high-fat meat, high-fat cream desserts; low-fat salads, soups, cooked potatoes, vegetables with low-fat sauces, low-fat meat and low-fat 'cream' desserts.

The boxes of snacks consisted of high-fat, and low-fat, sweet and savory biscuits, in the four possible combinations. All these are normal food items in the Netherlands, and all food items were liked by the subjects (hedonic scores: 78 ± 7 mm on a 100 mm Visual Analogue Scale).

Each time the subject received one of the four following treatments during 2 days, in random order, 30 min before each meal: 0.9 g red pepper (0.25% capsaicin; 80 000 Scoville Thermal Units, commercially available; highest suggested dosage) either in 200 ml of tomato juice or in two capsules, or placebo (200 ml plain tomato juice or plain capsules). When capsules were offered, these were swallowed with 200 ml tomato juice. Spiciness and hedonics of the juice was recorded every time it was offered.

Before the dosage was confirmed, the spiciness of the red pepper in tomato juice was assessed. Subjects got offered two series of concentrations of 0.00, 0.05, 0.1, 1, 2, 4, 5, 6, 8, 10 and 12 g/l red pepper in tomato juice in random order: the first series contained the concentrations from 0.00 to 8 g/l; the second series contained the concentrations from 6 to 12 g/l. It was given in two separate series on separate days in order not to disturb the scores by offering a juice that was too spicy. In between two drinks, subjects had a piece of white bread and a sip of carbonated mineral water. Subjects scored the spiciness and hedonics of each drink. Spiciness was increased significantly compared to plain juice at a concentration of 0.1 g/l (17 ± 3 mm VAS *vs* 4 ± 2 mm VAS; $P < 0.05$); they found it very spicy at 6.0 g/l (64 ± 7 mm VAS), and they found it too spicy at 12.0 g/l (92 ± 8 mm VAS). Subjects indicated that scores of 15–50 mm VAS represented a clear detection of spiciness; from 50 to 80 mm VAS, scores represented a very spicy solution and scores of 80–100 mm VAS represented that the solution was too spicy. The hedonics were not significantly different from each other for the concentrations 0.00–5 g/l (72±5 mm VAS (5 g/l red pepper in tomato juice) and 77±6 mm VAS (plain tomato juice or 0.05 g/l red pepper in tomato juice). The hedonics were reduced when more than 6 g/l red pepper was added (range: 60.2±5 mm VAS–32.0±6 mm VAS) ($P<0.01$). These results are in the same range as was reported by Craft and Porcera.[22]

The tomato juice with capsaicin that we chose to offer during the experiment contained 4.5 g/l red pepper, since it was the highest suggested dosage and since it was scored as more spicy (42±6 mm VAS) than the plain tomato juice (4±2 mm VAS), $P<0.01$, while the hedonics did not differ significantly between the juices (see above). After the experiments, the subjects scored their detection threshold, spiciness sensations and hedonics again in the same way as was executed before the experiments.

Hunger and satiety were recorded nine times throughout the day: before and after breakfast, lunch and dinner; mid-morning, mid-afternoon and in the evening, using Visual Analogue Scales. Energy intake, weight of food intake, macronutrient composition and energy density was assessed for every experimental day, and averaged over the 2 consecutive experimental days per treatment.

Data analysis

Data are presented as means±standard deviation (s.d.). A repeated measure ANOVA was carried out to determine possible differences between the four treatments. *Post hoc* analyses were carried out with the Scheffe *F*-test. Area under the curve (AUC) was determined for satiety and for hunger over 16 h/day, using the trapezoidal method. These measurements were averaged over the 2 consecutive experimental days. Regression analysis was used to assess whether possible differences due to treatment, that is, energy intake and satiety were dependent on BMI, or on spiciness perception. Moreover, possible responses with respect to energy intake and satiety were compared between the normal weight (BMI: 20–25 kg/m^2) and the overweight (BMI: 25–30 kg/m^2).

A *P*-value <0.05 was regarded as statistically significant. Statistical procedures were performed using Statview SE, Graphics (Abacus Concepts, Berkeley, CA, USA, 1988).

Results

In the men as well as the women, average daily energy intake over 2 days was 10–16% lower after consuming 0.9 g red pepper (0.25% capsaicin; 80 000 STU) before each meal, that is, it was 10±1% lower after red pepper in capsules, and 16±2% lower after red pepper in tomato juice ($P<0.01$) (see Figure 1).

When capsaicin was ingested in the juice, energy intake was more strongly reduced than when capsaicin was ingested in capsules ($P<0.05$) (see Figure 1).

In both capsaicin conditions as compared to placebo, the macronutrient composition of the 16 h food intake was different; the percentage energy from carbohydrate increased and from fat decreased ($P<0.01$) (see Figure 2).

Consequently, energy density of the 16 h food intake decreased after capsaicin ingestion compared to placebo ($P<0.01$) (see Figure 3).

Changes in the weight of the food ingested were not statistically significant (see Tables 1 and 2).

The reduction in energy intake took place at lunch and at dinner, as did the changes in macronutrient composition and the reduction in energy density. No changes in these variables occurred at breakfast or with snacks (Tables 1 and 2).

The reduction in average daily energy intake was related to food choice and thereby resulted in a change in macronutrient composition. Reduction in energy intake was related to the increase in en% CHO as well as to the decrease in en%

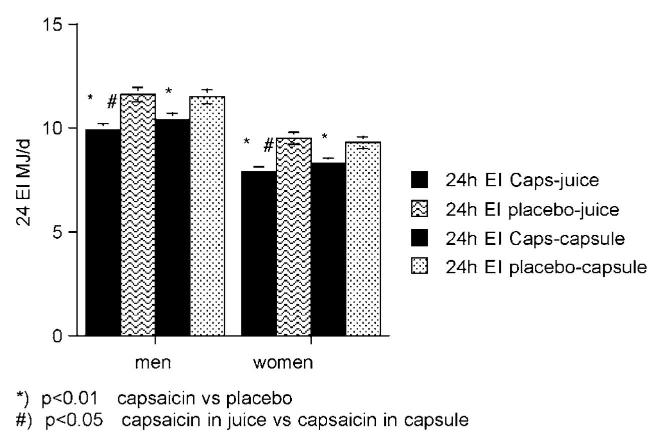

Figure 1 Average daily energy intake over 2 days (MJ/d) in men and women ($n=24$; 35±10 y; BMI: 25.0±2.4 kg/m^2), with capsaicin ingestion 30 min previous to each meal, in tomato juice *vs* plain tomato juice or in capsules *vs* placebo capsules, swallowed with tomato juice.

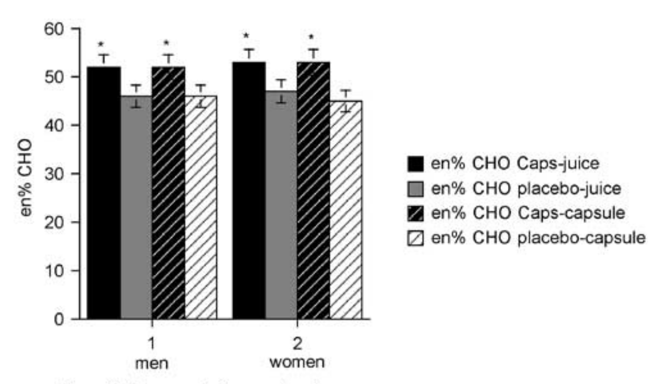

Figure 2 Percentage energy from carbohydrate of food intake in men and women ($n=24$; 35±10 y; BMI: 25.0±2.4 kg/m^2), averaged over 2 days, with capsaicin ingestion 30 min previous to each meal, in tomato juice *vs* plain tomato juice or in capsules *vs* placebo capsules, swallowed with tomato juice.

F ($r^2 = 0.7$; $P < 0.001$). Moreover, it was related to the decrease in energy density ($r^2 = 0.8$; $P < 0.001$).

AUC for satiety increased after capsaicin ingestion from 689±22 to 757±26 mmh in the men and from 712±24 to 806±27 mmh in the women, both ($P < 0.01$) (see Figure 4).

AUC for hunger decreased after capsaicin ingestion from 912±24 to 846±27 mmh in the men and from 890±25 to 797±26 mmh in the women, both ($P < 0.01$) (Figure 5).

The reductions in energy intake and satiety were not related to BMI. Moreover, these responses did not differ significantly between the subjects with a BMI of 20–25 or 25–30 kg/m^2.

In the situation where capsaicin was dissolved in the juice, the decrease in energy intake was related to perceived spiciness ($r = 0.66$; $P < 0.01$) and so was the increase in satiety ($r = 0.69$; $P < 0.01$). When capsaicin was given in capsules, these relationships were not significant ($r = 0.34$; $P > 0.5$ and $r = 0.37$; $P > 0.5$).

The tomato juice with capsaicin contained 1.125 mg/l capsaicin. It was scored as more spicy (42±6 mm VAS) than the plain tomato juice (4±2 mm VAS), $P < 0.01$. The hedonics did not differ significantly between the juices (72±5 mm VAS (capsaicin in tomato juice) and 77±6 mm VAS (plain tomato juice)) (NS). The detection threshold, spiciness scores and hedonics of the drinks did not change significantly after the experiment as compared to before the experiment (data not shown).

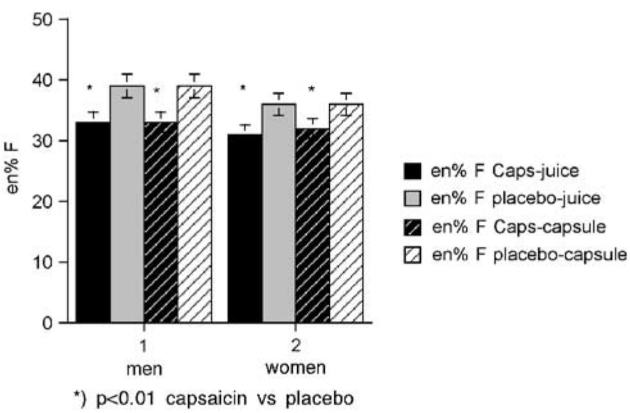

Figure 3 Percentage energy from fat of food intake in men and women ($n = 24$; 35±10 y; BMI: 25.0±2.4 kg/m^2), averaged over 2 days, with capsaicin ingestion 30 min previous to each meal, in tomato juice *vs* plain tomato juice or in capsules *vs* placebo capsules, swallowed with tomato juice.

Discussion

After consuming an appetizer with 0.9 g red pepper, containing 0.25% capsaicin (80 000 Scoville Thermal Units), before each meal, subjects decreased their energy intake, averaged over 2 subsequent days by 10–16%. The decrease in energy intake was 10–12% when the capsaicin was ingested in capsules that were swallowed with tomato juice, and around 16% when it was ingested in tomato juice. The dosage was the highest recommended dosage. When the red pepper was dissolved in the tomato juice, the juice was significantly

Table 1 Energy and weight (g) of food intake per meal and snacks in men ($n = 12$; 35±10 y; BMI: 25.0±2.6 kg/m^2), averaged over 2 days, during breakfast, lunch, dinner and in the form of snacks (EI in MJ), including macronutrient composition (C (carbohydrate)/P (protein)/F (fat) in percentage of energy (en%) and energy density (kJ/g)). In all, 12 men, with capsaicine ingestion 30 min previous to each meal, in tomato juice *vs* plain tomato juice or in capsules *vs* placebo capsules, swallowed with tomato juice

Treatment	*Capsaicin juice*	*Placebo juice*	*Capsaicin capsule*	*Placebo capsule*
Breakfast				
EI	2.0±0.3	2.1±0.3	2.1±0.3	2.1±0.3
C/P/F	52±3/15±1/33±2	50±3/15±1/35±2	52±2/15±1/33±2	50±3/15±1/35±3
ED	3.5±0.4	3.6±0.4	3.5±0.4	3.6±0.4
g	571.4±84.3	583.3±89.6	600.5±91.1	583.4±90.1
Lunch				
EI	3.0±0.4*	3.7±0.3	3.2±0.4*	3.7±0.4
C/P/F	53±5/15±1/32±3*	43±5/15±1/42±5	53±5/15±1/32±4*	42±4/15±1/43±3
ED	3.4±0.5*	4.0±0.7	3.4±0.4*	4.1±0.8
g	882.4±112.7	925.2±118.4	941.2±119.4	902.4±113.7
Dinner				
EI	3.9±0.4*	4.7±0.4	4.1±0.3*	4.6±0.4
C/P/F	52±5/15±1/33±3*	42±5/15±1/44±4	52±4/15±1/33±4*	41±4/15±1/44±4
ED	3.5±0.5*	4.2±0.6	3.5±0.5*	4.2±0.6
g	1114.3±142.3	1119.1±141.2	1171.4±149.8	1095.2±137.8
Snacks				
EI	1.0±0.05	1.1±0.06	1.0±0.06	1.1±0.05
C/P/F	51±1/14±1/35±1	50±1/14±1/36±1	51±1/14±1/35±1	51±1/14±1/35±1
ED	3.7±0.1	3.8±0.1	3.7±0.1	3.7±0.1
g	270.3±21.2	289.5±20.2	270.4±22.4	297.3±22.9

*$P < 0.01$ *vs* placebo.

Table 2 Energy intake and weight (g) per meal and from snacks in women ($n=12$; 35 ± 10 y; BMI: $25.0\pm2.2\,kg/m^2$), averaged over 2 days, during 16 h (EI in MJ), including macronutrient composition (C (carbohydrate)/P (protein)/F (fat) in percentage of energy (en%), and energy density (kJ/g)), with capsaicin ingestion 30 min previous to each meal, in tomato juice *vs* plain tomato juice or in capsules *vs* placebo capsules, swallowed with tomato juice

Treatment	*Capsaicin juice*	*Placebo juice*	*Capsaicin capsule*	*Placebo capsule*
Breakfast				
EI	1.5±0.3	1.6±0.3	1.6±0.3	1.6±0.3
C/P/F	55±2/15±1/30±2	53±2/15±1/32±2	55±2/15±1/30±2	53±2/15±1/32±3
ED	3.2±0.3	3.3±0.3	3.3±0.3	3.3±0.3
g	469.2±64.3	485.9±68.2	485.6±62.7	485.7±66.2
Lunch				
EI	2.0±0.4*	2.7±0.3	2.2±0.4*	2.7±0.4
C/P/F	53±4/15±1/32±3*	48±4/15±1/37±4	53±4/15±1/32±4*	48±4/15±1/37±3
ED	3.0±0.5*	3.4±0.7	3.0±0.4*	3.5±0.8
g	667.7±135.4	794.1±128.3	733.1±132.6	771.4±138.7
Dinner				
EI	3.4±0.3*	4.2±0.4	3.5±0.4*	4.0±0.4
C/P/F	55±4/15±1/30±3*	47±4/15±1/38±4	53±4/15±1/32±4*	47±4/15±1/38±4
ED	3.0±0.5*	3.5±0.6	3.0±0.5*	3.5±0.6
g	1133.8±144.2	1202.5±146.3	1168.4±149.0	1143.7±142.2
Snacks				
EI	1.0±004	1.0±004	1.0±0.04	1.0±0.04
C/P/F	55±2/14±1/31±1	55±2/14±1/31±2	55±1/14±1/31±2	55±2/14±1/31±2
ED	3.0±0.1	3.0±0.1	3.0±0.1	3.0±0.1
g	334.1±23.1	333.6±22.7	333.7±21.9	333.0±20.8

*$P<0.01$ treatment *vs* placebo.

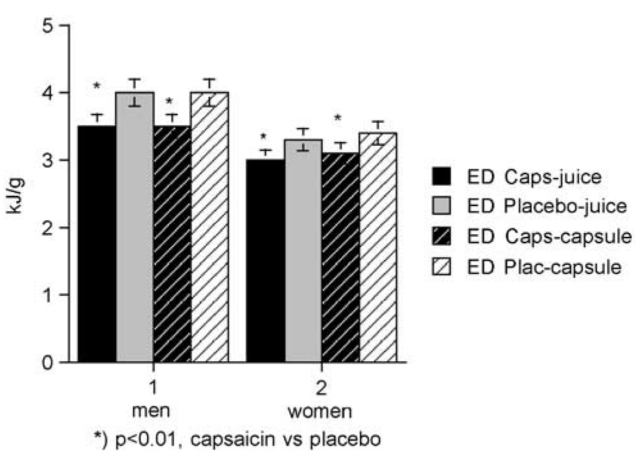

Figure 4 Energy density of food intake in kJ/g in men and women ($n=24$; 35 ± 10 y; BMI: $25.0\pm2.4\,kg/m^2$), averaged over 2 days, with capsaicin ingestion 30 min previous to each meal, in tomato juice *vs* plain tomato juice or in capsules *vs* placebo capsules, swallowed with tomato juice.

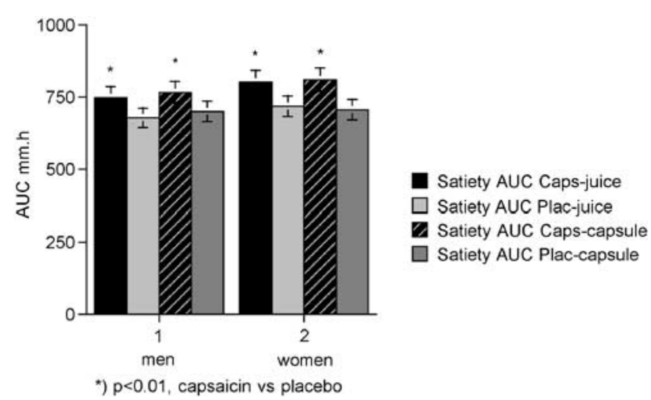

Figure 5 Satiety (mm h) AUC over 16 h in men and women ($n=24$; 35 ± 10 y; BMI: $25.0\pm2.4\,kg/m^2$), averaged over 2 days, with capsaicin ingestion 30 min previous to each meal, in tomato juice *vs* plain tomato juice or in capsules *vs* placebo capsules, swallowed with tomato juice.

spicier than the plain tomato juice, yet not very or too spicy, and the hedonics were not different. Thus, the sensory perception of capsaicin reduced energy intake even further than the gastrointestinal administration did. This was underscored by the relationships between perceived spiciness and the reduction in energy intake or the increase in satiety, but only after ingesting the capsaicin in tomato juice. This phenomenon may be possible since it has been shown that neurons in the orbitofrontal cortex can be specifically tuned to capsaicin.[23] In addition, to this separate representation, other neurons responded to combinations of inputs including capsaicin, thereby providing a rich representation of the sensory properties of food in the mouth.[23]

The reduction in energy intake was clearly related to a change in food choice. Subjects chose more carbohydrate-rich foods and less fat-rich foods from the macronutrient-specific buffet-style meals, thus decreasing energy density of food intake without changing weight of food intake.

Surprisingly, satiety was increased even while energy intake was decreased. It is likely that the stimulation of the

SNS activity stimulates the diet-induced thermogenesis and satiety, respectively.[16–18,21,24,25] Stimulation of metabolic satiety during the cephalic phase has been shown[26–28] and may contribute to treatment of overweight. However, it has been shown by Matsumoto *et al*[29] that the stimulation of SNS activity in Japanese obese subjects was blunted. In our study, there was no difference in the effects between the overweight and the normal weight subjects, so it still may work in overweight subjects.

In Japanese women, a decrease in energy intake also appeared from a decrease in fat intake, but it was not observed in Caucasian men.[17,18] Here, we observed a decreased fat intake in both Caucasian men and women.

When we discuss our present findings in a longer-term perspective, we speculate that the increased diet-induced thermogenesis may increase fat oxidation, since the priority in substrate oxidation (protein, carbohydrate, fat)[21] suggests that with a higher thermogenesis, fat oxidation will take place earlier, that is, before the start of the next meal, and thus be increased. We found an increased fat oxidation after 3 months treatment with capsaicin, suggesting a sustained mechanism without adaptation.[25]

Nevertheless, we have also previously shown that despite a sustained fat oxidation and a sustained resting energy expenditure, weight maintenance after weight loss was not supported by using red pepper three times daily,[25] probably due to long-term lack of compliance.[25]

A solution for applying the short-term effects of capsaicin on long-term weight management may be using a sweet, nonpungent red pepper, a cultivar named CH-19 sweet pepper.[30,31] Ohnuki *et al*[31] showed that CH-19 sweet increased oxygen consumption as well as body temperature in humans, also suggesting SNS-stimulating effects. We suggest to repeat the clinical studies on satiety and metabolism with the CH-19 sweet red pepper in humans.

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