

Effects of red pepper on appetite and energy intake

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Two studies were conducted to investigate the effects of red pepper (capsaicin) on feeding behaviour and energy intake. In the first study, the effects of dietary red pepper added to high-fat (HF) and high-carbohydrate (HC) meals on subsequent energy and macronutrient intakes were examined in thirteen Japanese female subjects. After the ingestion of a standardized dinner on the previous evening, the subjects ate an experimental breakfast (1883 kJ) of one of the following four types: (1) HF; (2) HF and red pepper (10 g); (3) HC; (4) HC and red pepper. *Ad libitum* energy and macronutrient intakes were measured at lunch-time. The HC breakfast significantly reduced the desire to eat and hunger after breakfast. The addition of red pepper to the HC breakfast also significantly decreased the desire to eat and hunger before lunch. Differences in diet composition at breakfast time did not affect energy and macronutrient intakes at lunch-time. However, the addition of red pepper to the breakfast significantly decreased protein and fat intakes at lunch-time. In Study 2, the effects of a red-pepper appetizer on subsequent energy and macronutrient intakes were examined in ten Caucasian male subjects. After ingesting a standardized breakfast, the subjects took an experimental appetizer (644 kJ) at lunch-time of one of the following two types: (1) mixed diet and appetizer; (2) mixed diet and red-pepper (6 g) appetizer. The addition of red pepper to the appetizer significantly reduced the cumulative *ad libitum* energy and carbohydrate intakes during the rest of the lunch and in the snack served several hours later. Moreover, the power spectral analysis of heart rate revealed that this effect of red pepper was associated with an increase in the ratio sympathetic:parasympathetic nervous system activity. These results indicate that the ingestion of red pepper decreases appetite and subsequent protein and fat intakes in Japanese females and energy intake in Caucasian males. Moreover, this effect might be related to an increase in sympathetic nervous system activity in Caucasian males.

Red pepper: Appetite: Energy intake: Sympathetic nervous system activity

Dietary fat intake has markedly increased with industrialization in many countries (Leaf & Weber, 1987). Experimental (Lissner *et al.* 1987; Tremblay *et al.* 1989, 1991) and cross-sectional (Lissner *et al.* 1987; Tremblay *et al.* 1989, 1991) studies have demonstrated that a higher fat content in the diet is associated with an increase in daily energy intake. This is not without consequence since high fat intake seems to be associated with increased body fatness (Dreon *et al.* 1988; Romieu *et al.* 1988). Warwick & Schiffman (1992) reviewed the literature related to the role of dietary fat in energy intake and body-weight gain in human subjects and laboratory animals. They concluded that both energy intake and expenditure are modified to favour positive energy balance when a high-fat (HF) diet is consumed and that the high energy density of HF diets plays a primary role in weight gain. This effect of HF intake on

energy and lipid balance might be explained by the fact that experimental evidence supports the idea that high-carbohydrate (HC) diets are more satiating than HF diets (Thomas *et al.* 1992; Blundell *et al.* 1993; Lawton *et al.* 1993; Stubbs *et al.* 1995) and that the reduction of fat intake when fat is replaced by a fat substitute does not result in increased hunger or full compensation of decreased energy intake (Westerterp-Plantenga *et al.* 1997). Therefore, it could be concluded that a HF diet is characterized by a lower potency to prevent overfeeding. From a public health standpoint, the overfeeding resulting from a HF dietary regimen probably represents one of the factors responsible for the high prevalence of obesity observed in industrialized countries.

Capsaicin, which is the major pungent principle in hot red pepper, has long been used as an ingredient of spices all over

Abbreviations: HC, high carbohydrate; HF, high fat; SNS, sympathetic nervous system.

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the world. Kawada and colleagues (Kawada *et al.* 1986) have reported that the addition of capsaicin to a HF diet lowers perineal adipose tissue weight in rats in a dose-dependent manner. We have also reported that the addition of capsaicin to a HC diet results in a reduction of the epididymal adipose tissue weight at the same energy intake (Matsuo *et al.* 1996). These results indicate that addition of capsaicin to foods could reduce adiposity, a phenomenon which can be explained partly by the enhancing effects of capsaicin on energy and lipid metabolism via catecholamine secretion from the adrenal medulla in rats (Watanabe *et al.* 1987*a,b*; Kawada *et al.* 1988). Since an increase in sympathetic nervous system (SNS) activity affects food intake behaviour (Russek *et al.* 1987; Bray, 1991; Raben *et al.* 1996), we hypothesized that the addition of red pepper (capsaicin) to the diet can decrease food intake and that this is associated with an increase in SNS activity. Specifically, in a first study we investigated whether the addition of red pepper to breakfasts of differing macronutrient composition could influence subsequent food intake and subjective feelings of hunger and satiety. Moreover, in order to document further the effects of red pepper on human eating behaviour, we performed a second study to investigate whether the addition of red pepper to an appetizer could influence subsequent food intake and whether this effect is related to concomitant changes in SNS activity.

Methods

Studies 1 and 2 were designed to test the impact of red pepper in real-life settings. In Study 1, we wanted to measure the impact of red pepper (capsaicin) added to meals (in this case breakfast meals) of differing macronutrient composition (HF *v.* HC) on subsequent subjective feelings of hunger and satiety as well as on subsequent *ad libitum* energy and macronutrient intakes at lunch-time (3 h following this test meal). Study 2 was designed to measure the impact of a preload (appetizer) with or without red pepper on *ad libitum* energy and macronutrient intakes immediately after consumption of this preload. Since many authors have tested similar hypotheses with a test meal given at breakfast time (see, for example, Blundell *et al.* 1993), we decided to adopt the same procedure. In order to be concordant with Study 1, we then had to measure *ad libitum* food intake after the appetizer at lunch-time. In a sense, we did not aim to reproduce the results of Study 1 with those of Study 2; rather we wanted to document further the impact of red pepper on human *ad libitum* food consumption. This is the main reason for the apparent differences of design between Studies 1 and 2.

Study 1

Subjects. Thirteen healthy Japanese females (age 25.8 (SD 2.8) years, weight 54.2 (SD 6.4) kg, height 1.57 (SD 0.04) m, body fat 25.3 (SD 4.7)%) volunteered to participate in this study. The participants were asked to maintain their regular dietary habits and to abstain from intake of alcohol and caffeine on the day before the investigation. Strenuous physical activity was not allowed

for 2 d before each experimental session to prevent the stimulation of energy metabolism (Bielinski *et al.* 1985; Bahr *et al.* 1987; Tremblay *et al.* 1988). All subjects were tested during the follicular phase of the menstrual cycle. The written consent of each subject was obtained before admission to the study; experimental procedures conformed to the Declaration of Helsinki.

Experimental protocol and measurements. The experimental protocol of this study was designed to investigate the effects of red pepper added to HF and HC meals on subsequent energy and macronutrient intakes. A detailed description of the composition of the red pepper used (*Saemaul Kongjang 1*) is given in Table 1. The subjects consumed a standardized dinner (15, 25 and 60% energy from protein, fat and carbohydrate respectively) on the day before each session. On the next morning, they participated randomly in one of four test sessions which consisted of the measurements of energy and macronutrient intakes 3 h after the experimental meals, each of which provided 1883 kJ. These meals differed between sessions according to the following specifications: HF meal (% energy: protein 15, fat 45, carbohydrate 40), HF and red-pepper (10 g) meal, HC meal (% energy: protein 15, fat 25, carbohydrate 60), and HC and red-pepper meal. The subjects rested on a chair in a semi-reclining position for 3 h to perform calorimetric measurements after the meals. At lunch-time, the subjects were instructed to eat *ad libitum* in the laboratory until satiated. To facilitate the measurement of food intake, food was prepared and pre-portioned. After each meal, quantities of foods that were not entirely consumed were reweighed to determine net intake of each food. The Canadian Nutrient File 1991 software was used to calculate energy, protein, lipid and carbohydrate intakes from these measurements.

Prospective food consumption, desire to eat, hunger, fullness and satiety were measured immediately before and after the breakfast and lunch by using a 150 mm visual analogue scale, as further described in Table 2, which was adapted from the method previously described by Hill & Blundell (1986). All results obtained with the

Table 1. The composition of dried hot red pepper (Data from Ku & Choi, 1990)

Component	Content
Crude component (g/kg)	
Moisture	194
Protein	109
Fat	152
Carbohydrate	462
Ash	78
Capsaicin	3
Minerals (g/kg)	
Calcium	1230
Phosphorus	1400
Iron	1000
Vitamins (mg/kg)	
A	21.1
Thiamin	3
Riboflavin	2
C	2200
Metabolic energy (kJ/g)	10.1

Table 2. Description of the visual analogue scale used for measurement of prospective food consumption, desire to eat, hunger, satiety and fullness

Variable	Question
Prospective food consumption	1) How much food do you think you could eat? No food at all ----- A large amount
Desire to eat	2) How strong is your desire to eat? Very weak ----- Very strong
Hunger	3) How hungry do you feel? Not at all hungry ----- As hungry as I have ever felt
Satiety	4) What is your level of satiety? Not satiated at all ----- Very high
Fullness	5) How full do you feel? Not at all full ----- Very full

visual analogue scale were converted to scores ranging from 0 to 100 for statistical analysis.

Because elemental conditions and the physical state of foods affect spontaneous energy intake in human studies (Kissileff, 1985; Himaya & Louis-Sylvestre, 1998), precautions were taken to maximize the reliability of experimental conditions: subjects were given standardized instructions, the confounding effect of external factors such as light and noise was minimal, the time interval between meals was comparable in each session, and foods used were normally eaten by subjects.

Statistical analysis. A three-way ANOVA for repeated measures was used to determine effects of diet composition, red pepper and time as well as their interactions on prospective food consumption, desire to eat, hunger, fullness and satiety. We also used a two-way ANOVA to determine the effect of diet composition \times red pepper as well as the diet composition \times red pepper interaction on energy and macronutrient intakes. When the ANOVA revealed a significant effect, a contrast analysis adjusting for multiple comparisons was applied to identify which conditions differed from each other. Differences were considered to be statistically significant at $P < 0.05$. Statistical analyses were performed with SuperAnova Software, version 1.11, © Abacus Concepts, Inc. 1991, Cary, NC, USA. All results are expressed as means with their standard errors.

Study 2

Subjects. Ten healthy Caucasian males (age 32.9 (SD 7.8) years, weight 72.5 (SD 10.1) kg, height 1.75 (SD 0.06) m) volunteered to participate in this study. The instructions to participants were the same as those in Study 1. The written consent of each subject was obtained before admission to the study; experimental procedures conformed to the Declaration of Helsinki.

Experimental protocol and measurements. The experimental protocol of this study was designed to investigate the effects of an appetizer containing red pepper on subsequent energy and macronutrient intakes. The subjects consumed a standardized breakfast (% energy: protein 18, fat 39, carbohydrate 43) and they participated randomly in the two test sessions which consisted of measurement of *ad libitum* energy and macronutrient intakes after the

experimental appetizers at lunch-time. In each session, the energy content of the appetizer was 644 kJ (% energy: protein 15, fat 29, carbohydrate 56) and it differed only in red pepper content (0 v. 6 g red pepper). After consuming the appetizer, the subjects were instructed to eat *ad libitum* until satiety was reached. A snack was also offered in the middle of the afternoon (3 h after lunch) and the subjects were again instructed to eat *ad libitum*. The procedures to measure food intake were identical to those used in Study 1.

Heart-rate power spectral analysis was performed throughout the experiment using an electrocardiograph (Q4000 Quinton, Seattle, WA, USA). The electrocardiographic signals were digitized, stored on hard disk and sampled at a rate of 500 Hz, with twelve precision bits. The QRS complex (lead II) was automatically recognized by a classic derivative/threshold algorithm. Power spectra were calculated from a consecutive series of 512 R-R intervals. As previously reported (Pomeranz *et al.* 1985; Arai *et al.* 1989), the ratio low-frequency (0.04–0.15 Hz Eq):high-frequency (0.15–0.50 Hz Eq) components of spectra was used as an indicator of the ratio sympathetic:parasympathetic nervous system activity. It has been reported that the intra-individual CV of heart-rate spectral analysis measured four times over 27 d was 16.7% (Hirsch *et al.* 1991). It has also been found that this method provides realistic information about changes in SNS activity in the context of experimental overfeeding and underfeeding (Aronne *et al.* 1995).

Statistical analysis. A two-way ANOVA for repeated measures was used to determine effects of red pepper and time as well as their interactions on dependent variables, whereas a three-way ANOVA was used to determine the effects of time, red pepper, diet composition, and their interaction on prospective food consumption, desire to eat, hunger, fullness and satiety. When the ANOVA revealed a significant effect, a contrast analysis adjusting for multiple comparisons was applied to identify which conditions differed from each other. Pearson's correlation coefficients were calculated to quantify the associations between changes in energy intake and those derived from the power spectral analysis of heart rate. Differences were considered to be statistically significant at $P < 0.05$. Statistical analyses were performed with SuperAnova Software, version 1.11, © Abacus Concepts, Inc. 1991.

All results are expressed as means with their standard errors.

Results

Study 1

Effects of red pepper added to HF and HC breakfasts on energy and macronutrient intakes are presented in Table 3. The macronutrient composition of breakfast did not affect the weight of ingested food, or energy and macronutrient intakes at lunch-time. However, the addition of red pepper to breakfast significantly decreased protein intake (by 20% and 6% for HF and HC conditions respectively, $P < 0.05$) and fat intake (by 17% and 11% for HF and HC conditions respectively, $P < 0.05$) at lunch-time. Red pepper also tended to decrease energy intake (11% and 4% for HF and HC conditions respectively) but this effect did not reach statistical significance.

Variations in prospective food consumption, desire to eat, hunger, fullness and satiety as measured by visual analogue scales are shown in Fig. 1. Prospective food consumption was significantly higher in the HF meal condition immediately after the breakfast and before the lunch. The addition of red pepper to experimental meals significantly decreased the prospective food consumption immediately before the lunch whereas the opposite effect was seen after the lunch. Desire to eat was significantly higher in the HF meal conditions immediately after the breakfast, but red pepper corrected this effect by significantly decreasing the desire to eat immediately after the breakfast and before the lunch. Hunger was significantly higher in the HF meal conditions immediately after the breakfast and the addition of red pepper to the experimental meals significantly decreased this variable immediately after the breakfast and before the lunch. Fullness and satiety were not significantly modified by the experimental meals.

Study 2

The effects of the red-pepper appetizer on energy and macronutrient intakes are shown in Table 4; these values do not include the energy and macronutrient content of the appetizer. The addition of red pepper to the experimental appetizer significantly decreased cumulative (lunch + mid-afternoon snack) carbohydrate intake (18%, $P < 0.05$) and energy intake (11%, $P < 0.05$) at lunch and snack.

Fig. 2 presents changes in the sympathetic:parasympathetic nervous system activity ratio as reflected by changes in the low:high frequency ratio of the power spectra as measured by power spectral analysis of heart rate. The addition of red pepper to the experimental appetizer significantly increased the sympathetic:parasympathetic nervous system activity ratio during and immediately after the appetizer ingestion. However, there was no further effect of the red pepper appetizer during or after the *ad libitum* lunch.

The correlation between changes in the sympathetic:parasympathetic nervous system activity ratio from baseline and energy intake is shown in Fig 3. Changes in the sympathetic:parasympathetic nervous system activity ratio tended to be negatively correlated with energy intake, but this effect failed to reach standard statistical significance ($P = 0.09$).

In the two studies, no subject reported nausea or any other unpleasant effects related to red pepper ingestion. Although this issue was not investigated with specific questions, the absence of unpleasant sensations related to red-pepper ingestion suggests that its effects were not explained by a transitory discomfort under the red-pepper condition.

Discussion

The results of these studies indicate that the ingestion of red pepper decreases subsequent protein and fat intakes as well as appetite in Japanese females. In Caucasian males, red-pepper ingestion reduces spontaneous energy intake, an effect which might be related to an increase in SNS activity. Addition of capsaicin to the diet is known to affect energy metabolism by activating the SNS in animals (Watanabe *et al.* 1987a,b; Kawada *et al.* 1988), and an increase in SNS activity is known to favour a decrease in food intake (Russek *et al.* 1987; Bray, 1991; Raben *et al.* 1996). In the present study, we investigated the effects of dietary red pepper on energy and macronutrient intakes. The impact of diet composition on feeding behaviour and subsequent energy intake was also examined.

Effect of diet composition on food intake behaviour

In Study 1, the desire to eat and the level of hunger immediately after the HF breakfast were greater than those observed after the HC breakfast. The prospective food consumption was also greater immediately after the

Table 3. Study 1. Energy and macronutrient intakes at lunch-time after the ingestion of a high-fat (HF), HF red-pepper (HF+RP), high-carbohydrate (HC) or HC red-pepper (HC+RP) breakfast*
(Mean values and standard deviations for thirteen subjects)

Breakfast ...	HF		HF + RP		HC		HC + RP		Significant effect†
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	
Food intake (g)	786	66	702	76	768	67	738	80	
Protein intake (g)	28.6	3.7	22.9	3.5	28.3	4.0	26.6	4.3	RP
Fat intake (g)	29.6	3.1	24.7	3.0	29.2	3.3	26.1	3.4	RP
Carbohydrate intake (g)	104.3	13.5	100.0	13.2	101.8	12.6	103.3	11.9	
Energy intake (kJ)	3340	381	2988	352	3281	368	3155	356	

* For details of meals and procedures, see pp. 116–117.

† Significant effect determined by two-way ANOVA, $P < 0.05$. There was no significant diet × RP interaction.

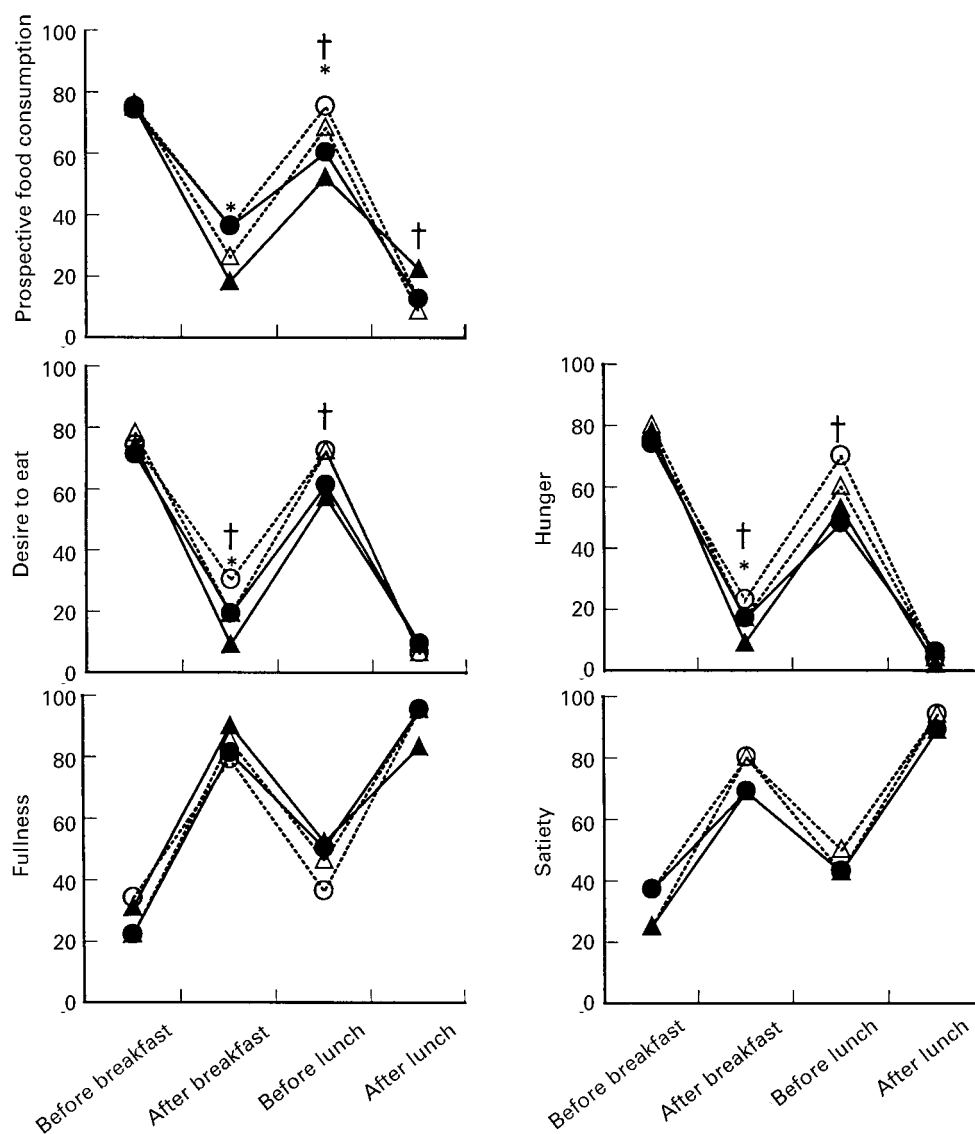


Fig. 1. Study 1. Values for prospective food consumption, desire to eat, hunger, fullness and satiety, measured by a visual analogue scale (Table 2), immediately before and after high-fat and high-carbohydrate breakfasts with or without red pepper, and before and after a subsequent lunch-time meal. The breakfasts were: (---○---), high fat; (—●—), high fat plus red pepper; (---△---), high carbohydrate; (—▲—), high carbohydrate plus red pepper. Values are means for thirteen subjects. There was a significant effect of diet composition by three-way ANOVA, * $P < 0.05$, and a significant effect of red pepper by three-way ANOVA, † $P < 0.05$.

Table 4. Study 2. Energy and macronutrient intakes at lunch-time and snack time after the ingestion of a control or red-pepper (RP) appetizer* (Mean values and standard deviations for ten subjects)

	Control appetizer				Red-pepper appetizer				Significant effect†
	Lunch		Snack		Lunch		Snack		
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	
Food intake (g)	979	94	373	94	943	70	290	73	T
Protein intake (g)	52.8	7.2	7.1	1.9	46.7	6.7	8.3	2.5	T
Fat intake (g)	65.6	3.2	13.4	3.2	62.3	6.7	13.7	3.9	T
Carbohydrate intake (g)	133.5	10.5	60.8	13.5	112.8	9.8	45.8	12.0	T, RP
Energy intake (kJ)	5583	598	1645	343	5018	456	1419	372	T, RP

T, time.

* For details of meals and procedures, see pp. 116–118.

† Significant effect determined by two-way ANOVA, $P < 0.05$. There was no significant $T \times RP$ interaction.

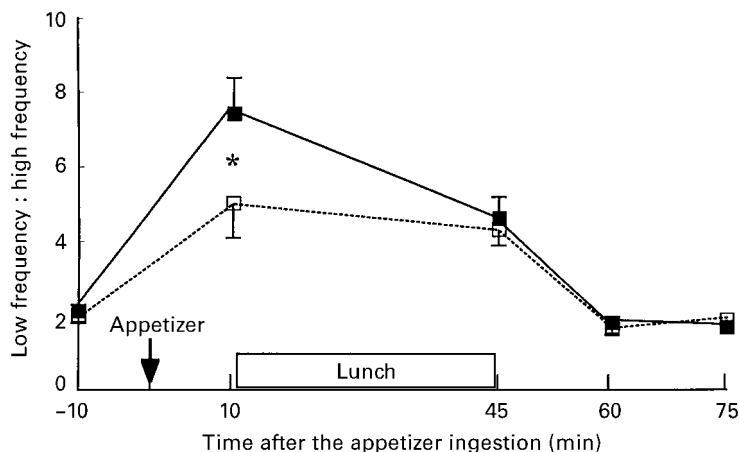


Fig. 2. Study 2. Values for the sympathetic : parasympathetic nervous system activity ratio (expressed as the low : high frequency ratio of the power spectra as measured by power spectral analysis of heart rate) before and after ingestion of a control appetizer (---□---) and an appetizer containing red pepper (---■---). Values are means for ten subjects, with their standard errors represented by vertical bars. There was a significant effect of red pepper determined by two-way ANOVA, * $P < 0.05$.

HF breakfast and before the lunch than for the HC breakfast condition. These results are in agreement with those of previous studies which demonstrated that HF foods have a weak potential to promote satiety acutely (Blundell *et al.* 1993; Lawton *et al.* 1993). However, the present results show that these changes were not associated with significant changes in *ad libitum* food and energy intakes at lunch-time. The lack of a statistically significant difference in energy intake might be due to the absence of a change in carbohydrate intake but may also be attributable to a type 2 error caused by a lack of statistical power due to the large between-subject variation in the response to the ingestion of red pepper.

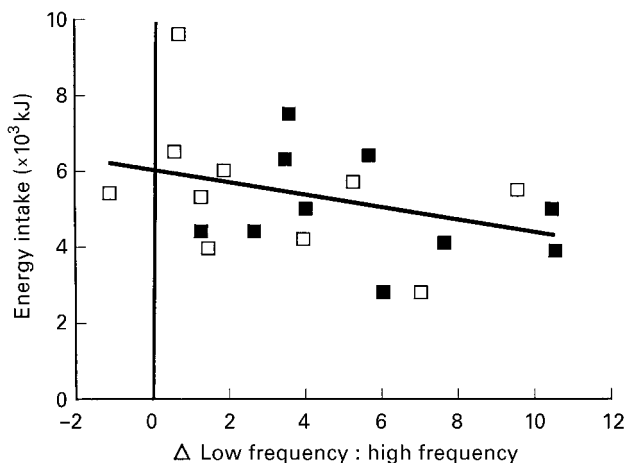


Fig. 3. Study 2. Correlation between changes in the sympathetic : parasympathetic nervous system activity ratio (expressed as the low : high frequency ratio of the power spectra as measured by power spectral analysis of heart rate) and energy intake at lunch-time and snack meals in subjects consuming a control appetizer (□) or an appetizer containing red pepper (■). Values were obtained in ten subjects who participated in two testing sessions. The relationship is described by the equation: $Y = -184.7X + 6070$ ($P = 0.0895$, $r = 0.390$).

Effect of red pepper on food intake behaviour

It is generally believed that red pepper is used for increasing appetite under conditions of high temperature and humidity during summer time in Japan. However, experimental evidence suggests that capsaicin has the potential to decrease food intake in animals, an effect that might be mediated by SNS activity (Watanabe *et al.* 1987a,b; Kawada *et al.* 1988). The addition of red pepper to breakfast significantly decreased protein and fat intakes at lunch-time in Study 1, and the red-pepper appetizer decreased carbohydrate and energy intakes in Study 2. Moreover, these changes in macronutrient intake were accompanied by changes in appetite such as decreased prospective food consumption, desire to eat and hunger in Study 1. This difference between popular belief and experimental data may be explained in part by the amount of the spice ingested. Indeed, high doses of capsaicin were used in the injection studies with rats (Watanabe *et al.* 1987a,b; Kawada *et al.* 1988) and in the studies where oral administration of capsaicin or red pepper was performed in rats or human subjects (Kawada *et al.* 1986; Yoshioka *et al.* 1995; Matsuo *et al.* 1996; Lim *et al.* 1997) compared with the habitual consumption in Japan. Therefore there is a possibility that a small to moderate level of red pepper in the diet might increase food intake. Since the number of papers which document the effects of red pepper in human subjects is quite limited, further research would be needed to clarify the effects of different doses of red pepper on food and/or energy intake.

Relationship between sympathetic nervous system activity and food intake behaviour

Bray (1993) has proposed that SNS activity affects food intake. Moreover, Raben *et al.* (1996) have recently demonstrated an association between postprandial noradrenaline

release and the appetite scores. Therefore, these observations imply that increasing SNS activity should result in a decrease in *ad libitum* food intake. In Study 2, the addition of red pepper to the experimental appetizer significantly decreased energy intake at lunch-time and significantly increased the sympathetic:parasympathetic nervous system activity ratio during and immediately after ingestion of the appetizer. Moreover, Δ sympathetic:parasympathetic nervous system activity ratio tended to be negatively correlated with energy intake. If we postulate that this change in the sympathetic:parasympathetic nervous system activity ratio reflects an increase in SNS activity, these results are in agreement with those of Russek *et al.* (1987) who demonstrated that catecholamines, especially adrenaline, have an anorectic effect that may be due to a modification of the hepatic metabolism. We have recently reported that there is a peak increase in catecholamine levels immediately after red-pepper ingestion (Lim *et al.* 1997) and that the increase in thermogenesis immediately after the ingestion of red pepper is abolished by a β -adrenergic blockade (Yoshioka *et al.* 1995). Thus, these changes in catecholamines might have also affected the feeding behaviour in the present studies. The latter observations suggest that spicy foods taken as an appetizer could be a successful prescription to decrease subsequent *ad libitum* energy intake and to increase thermogenesis, because spices such as red pepper increase SNS activity.

In summary, the addition of red pepper to a meal decreased the desire to eat as well as protein and fat intakes at the next meal in Japanese subjects. Moreover, the addition of red pepper to an appetizer at lunch-time decreased carbohydrate and energy intakes at lunch and snack meals in Caucasians. These changes in energy intake tended to be negatively correlated with the increase in the sympathetic:parasympathetic nervous system activity ratio as measured by power spectral analysis of heart rate. These results suggest that the addition of red pepper to the diet decreases energy intake, an effect which might be mediated by an increase in SNS activity.

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References

- Arai Y, Saul P, Albrecht P, Hartley LH, Lilly LS, Cohen RJ & Colucci WS (1989) Modulation of cardiac autonomic activity during and immediately after exercise. *American Journal of Physiology* **256**, H132–H141.
- Aronne LJ, Mackintosh R, Rosenbaum M, Leibel RL & Hirsch J (1995) Autonomic nervous system activity in weight gain and weight loss. *American Journal of Physiology* **269**, R222–R225.
- Bahr R, Inghes I, Vaage O, Sejersted OM & Newsholme EA (1987) Effect of duration of exercise on excess postexercise O₂ consumption. *Journal of Applied Physiology* **62**, 485–490.
- Bielinski R, Schutz Y & Jéquier E (1985) Energy metabolism during the postexercise recovery in man. *American Journal of Clinical Nutrition* **42**, 69–82.
- Blundell J, Burley VJ, Cotton JR & Lawton CL (1993) Dietary fat and control of energy intake: evaluating the effects of fat on meal size and postmeal satiety. *American Journal of Clinical Nutrition* **57**, 772S–778S.
- Bray G (1991) A disorder of nutrient partitioning: MONA LISA hypothesis. *Journal of Nutrition* **121**, 1146–1162.
- Bray GA (1993) Food intake, sympathetic activity, and adrenal steroids. *Brain Research Bulletin* **32**, 537–541.
- Dreon DM, Frey-Hewitt B, Ellsworth N, Williams PT, Terry RB and Wood PD (1988) Dietary fat:carbohydrate ratio and obesity in middle-aged men. *American Journal of Clinical Nutrition* **47**, 995–1000.
- Hill AJ & Blundell JE (1986) The effects of a high-protein or high-carbohydrate meal on subjective motivation to eat and food preferences. *Nutrition and Behavior* **3**, 133–144.
- Himaya A & Louis-Sylvestre J (1998) The effect of soup on satiation. *Appetite* **30**, 199–210.
- Hirsch J, Leibel RL, Mackintosh R & Aguirre A (1991) Heart rate variability as a measure of autonomic function during weight change in humans. *American Journal of Physiology* **261**, R1418–R1423.
- Kawada T, Hagihara K-I & Iwai K (1986) Effects of capsaicin on lipid metabolism in rats fed high fat diet. *Journal of Nutrition* **116**, 1272–1278.
- Kawada T, Sakabe S, Watanabe T, Yamamoto M & Iwai K (1988) Some pungent principles of spices cause the adrenal medulla to secrete catecholamine in anesthetized rats. *Proceedings of the Society for Experimental Biology and Medicine* **188**, 229–233.
- Ku Y & Choi S (1990) The composition of foods. In *The Scientific Technology of Kimchi*, pp. 33–34 [Korean Institute of Food Development, editors]. Seoul, Korea: Korean Institute of Food Development.
- Kissileff HR (1985) Effects of physical state (solid–liquid) of foods on food intake: procedural and substantive contributions. *American Journal of Clinical Nutrition* **42**, 956–965.
- Lawton CL, Burley VJ, Wales JK & Blundell JE (1993) Dietary fat and appetite control in obese subjects: weak effects on satiety. *International Journal of Obesity* **17**, 409–416.
- Leaf A & Weber PC (1987) A new era for science in nutrition. *American Journal of Clinical Nutrition* **45**, 1048–1053.
- Lim K, Yoshioka M, Kikuzato S, Kiyonaga A, Tanaka H, Shindo M & Suzuki M (1997) Dietary red pepper ingestion increased carbohydrate oxidation at rest and during exercise in runners. *Medicine and Science in Sports and Exercise* **29**, 355–361.
- Lissner L, Levitsky DA, Strupp BJ, Kalkwarf HJ & Roe DA (1987) Dietary fat and regulation of energy intake in human subjects. *American Journal of Clinical Nutrition* **46**, 886–892.
- Matsuo T, Yoshioka M & Suzuki M (1996) Capsaicin in diet does not affect glycogen contents in the liver and skeletal muscle of rats before and after exercise. *Journal of Nutritional Science and Vitaminology* **42**, 249–256.
- Pomeranz B, Macaulay RJB, Caudill MA, Kutz I, Adam D, Gordon D, Kilborn KM, Barger AC, Shannon DC, Cohen RJ & Benson H (1985) Assessment of autonomic function in humans by heart rate spectral analysis. *American Journal of Physiology* **248**, H151–H153.
- Raben A, Holst JJ, Christensen NJ & Astrup A (1996) Determinants of postprandial appetite sensations: macronutrient intake and glucose metabolism. *International Journal of Obesity* **20**, 161–169.
- Romieu I, Willett WC, Stampfer MJ, Colditz GA, Sampson L, Rosner B, Hennekens CH & Speizer FE (1988) Energy intake and other determinants of relative weight. *American Journal of Clinical Nutrition* **47**, 406–412.
- Russek M, Vega C, Berrera J, Soto-Mora LM, Langazorta A & Racotta R (1987) Anorexia elicited by different catecholamines in rats. *Appetite* **9**, 119–126.
- Stubbs RJ, Harbron CH, Murgatroyd PR & Prentice AM (1995)

- Covert manipulation of dietary fat and energy density: effect on substrate flux and food intake in men eating ad libitum. *American Journal of Clinical Nutrition* **62**, 316–329.
- Thomas CD, Peters JC, Reed GW, Abumrad NN, Sun M & Hill JO (1992) Nutrient balance and energy expenditure during ad libitum feeding of high-fat and high-carbohydrate diets in humans. *American Journal of Clinical Nutrition* **55**, 934–942.
- Tremblay A, Lavallée N, Alméras N, Allard L, Després JP & Bouchard C (1991) Nutritional determinants of the increase in energy intake associated with a high fat diet. *American Journal of Clinical Nutrition* **53**, 1134–1137.
- Tremblay A, Nadeau A, Fournier G & Bouchard C (1988) Effect of a three-day interruption of exercise training on resting metabolic rate and glucose-induced thermogenesis in trained individuals. *International Journal of Obesity* **12**, 163–168.
- Tremblay A, Plourde G, Després JP & Bouchard C (1989) Impact of dietary fat content and fat oxidation on energy intake in humans. *American Journal of Clinical Nutrition* **49**, 799–805.
- Warwick ZS & Schiffman SS (1992) Role of dietary fat in calorie intake and weight gain. *Neuroscience and Biobehavioral Reviews* **16**, 585–596.
- Watanabe T, Kawada T & Iwai K (1987a) Enhancement by capsaicin of energy metabolism in rats through secretion of catecholamine from adrenal medulla. *Agricultural and Biological and Chemistry* **51**, 75–79.
- Watanabe T, Kawada T, Yamamoto M & Iwai K (1987b) Capsaicin, a pungent principle of hot red pepper, evokes catecholamine secretion from the adrenal medulla of anesthetized rats. *Biochemical and Biophysical Research Communications* **142**, 259–264.
- Westerterp-Plantenga MS, Wijckmans-Duijsens NE, ten Hoor F & Weststrate JA (1997) Effect of replacement of fat by nonabsorbable fat (sucrose polyester) in meals or snacks as a function of dietary restraint. *Physiology and Behavior* **61**, 939–947.
- Yoshioka M, Lim K, Kikuzato S, Kiyonaga A, Tanaka H, Shindo M & Suzuki M (1995) Effects of red-pepper diet on the energy metabolism in men. *Journal of Nutritional Science and Vitaminology* **41**, 647–656.

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Appendix

Study 1

Table 1. Compositions of the high-fat and high-carbohydrate breakfast meals

Food	Weight (g)	Energy (kJ)	Protein (g)	Fat (g)	Carbohydrate (g)
High-fat breakfast					
Scallops	26.4	107.1	5.3	0.3	0.5
Green peppers	43.3	51.9	0.0	0.1	2.8
Onions	41.0	62.8	0.0	0.1	3.5
Tomatoes	42.3	38.9	0.0	0.1	2.0
Shrimps	20.1	94.6	4.4	0.4	0.2
Rice (cooked)	126.8	663.6	3.0	0.4	35.8
Bacon	37.0	698.7	4.1	16.6	0.3
Oil	4.4	165.7	0.0	4.4	0.0
Total: g	341.3		16.9	22.5	45.1
kJ		1883.2	282.0	846.5	754.7
(kcal)		(450.1)	(67.4)	(202.3)	(180.4)
% energy			15.0	44.9	40.1
High-carbohydrate breakfast					
Scallops	10.0	40.6	2.0	0.1	0.2
Green peppers	37.0	44.4	0.0	0.1	2.4
Onions	34.0	52.3	0.0	0.1	2.9
Tomatoes	65.5	59.8	0.0	0.2	3.1
Shrimps	38.0	178.2	8.4	0.8	0.4
Rice (cooked)	206.5	1080.7	5.0	0.6	58.2
Bacon	14.2	268.2	1.6	6.4	0.1
Oil	4.2	158.2	0.0	4.2	0.0
Total: g	409.4		16.9	12.5	67.4
kJ		1882.8	282.7	472.2	1127.8
(kcal)		(450.0)	(67.6)	(112.9)	(269.6)
% energy			15.0	25.1	59.9

Table 2. List of foods served (in large amounts) during the lunch-time buffet

Cola	Red apples	Cucumber
7-up®	Bananas	Lettuce
Apple juice	Oranges	Tomatoes
Orange juice	White bread	Sliced ham
Milk (3.5% fat)	Muffins	Brie cheese
Tea	Melba® toasts	Turkey
Oreo® cookies	White rice	Salami
Tea biscuits	Celery	Fish
Fruit yoghurt	Carrots	Nori (Japanese food)
Ketchup	Soya sauce	Chazuke (Japanese food)
Mustard	Butter	

Study 2

Table 3. Compositions of the red-pepper and control appetizers

Food	Weight (g)	Protein (g)	Fat (g)	Carbohydrate (g)
Red-pepper appetizer				
White bread	18	1.51	0.68	8.64
Tomatoes	10	0.07	0.01	0.33
Pimentoes	5	0.05	0.01	0.21
Cream cheese (regular)	8	0.85	1.33	0.32
Red pepper	3	0.33	0.46	1.39
Total: g	44.0	2.8	2.5	10.9
kJ	323.0	46.9	93.7	182.4
% energy	100.0	14.6	29.0	56.4
Control appetizer				
White bread	20.5	1.71	0.78	9.84
Tomatoes	10	0.07	0.01	0.33
Pimentoes	5	0.05	0.01	0.21
Cream cheese (regular)	10	1.07	1.67	0.40
Total: g	45.5	2.9	2.5	10.8
kJ	322.2	48.5	92.9	180.3
% energy	100.0	15.1	28.9	56.0

Table 4. Lists of foods served (in large amounts) during the lunch-time buffet

Turkey	Ketchup	Fudge
Salmon	White bread	Milk (1 % fat)
Pâté	Crackers	Milk (2 % fat)
Ham	(Premium plus®)	Milk (3.25 % fat)
Gruyère cheese	Lettuce	Orange juice
Mozzarella cheese	Tomatoes	Apple juice
Cottage cheese	Carrots	Cola
Butter	Oranges	7-up®
Mayonnaise	Apples	Crisps
Vinegar	Tea biscuits	(Ruffles® rippled)
Mustard	Fruit yoghurt	Water

Table 5. Lists of foods served (in large amounts) during the afternoon snack

Milk (2 % fat)	Chocolate cookies
Cola	Oreo® cookies
7-up®	Crackers (Premium plus®)
Quaker Dipp Bars®	Ritz® crackers
Crisps (Ruffles® rippled)	Tea biscuits