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High-fat diet-related stimulation of sweetness desire is greater in women than in men despite high vegetable intake

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Abstract

Objective: To examine the effects of lunches with different dietary energy densities on food preferences between genders.
Design: Randomized crossover study. Participants were administered the following packed test meals once weekly on a specified day during six sessions: control (150 g of rice with a sautéed beef entrée containing 40 g of raw beef and 240 g of vegetables), high-meat/low-rice, low-vegetable, medium-fat/low-vegetable, high-fat and high-fat/low-vegetable meals. Subjective levels of sensory properties were assessed over time using visual analogue scales.
Setting: University of Tokushima Graduate School, Tokushima, Japan.
Subjects: Sixty-five men and sixty-five women matched by age and BMI.
Results: Men showed significantly stronger desires for salty and fatty foods after meals ($P<0{\cdot}05$). Women showed a significantly stronger desire for sweetness from 2 h after the low-vegetable meal, and increasing fat content under high-vegetable conditions caused a significant stimulated sweetness desire in women more than in men ($P<0{\cdot}05$). Moreover, after a high-meat/low-rice meal with 100 g of rice, sweetness desire was stronger in women ($P=0{\cdot}024$), whereas no significant differences in sweetness desire were shown between genders after another low-energy-density control meal with 150 g of rice.
Conclusions: Men had significantly stronger desires for salty and fatty foods, whereas women preferred sweet food after meals. The sweetness desire in women was stimulated by increasing fat content, even with a high vegetable intake. Low rice intake in a low-energy-density diet also caused a relative stimulation of sweetness desire in women.

Keywords
Energy density
Food preference
Gender differences
Sweetness desire

Nutritional strategies that can prevent weight gain are considered to be a result of controlling appetite and energy intake during normal daily life[1]. Controlled studies show that energy intake is closely associated with the energy density (ED) of the diet, which enables individuals to consume a satisfying amount of food when it is lower in ED[2–4]. Thus, reducing the ED of the total diet may be a nutritionally sound strategy for the management of body weight[5].

Many factors affecting the sensory properties of food may contribute to the effects of ED on energy intake and eating behaviour as foods are consumed[6]. Because observational studies have indicated a relationship between food consumption and intensity of food taste[7], attention needs to be paid to the perceptions of food-related pleasantness as well as fullness and satisfaction after food intake.

The brain controls eating behaviour and it responds differentially to food depending on factors such as body mass[8], mood[9] and age[10]. Another potential factor that cannot be neglected regarding its effects on eating behaviour is the gender difference. Men and women often have different social perceptions regarding the sensory properties of food, because women pay more attention to nutrition content than men[11]. Despite numerous studies focusing on gender-related differences in behavioural and neuronal responses to food[12–14], little research has been published that compares specific sensory properties between genders with diet models of different ED.

Given the close association of sensory properties and dietary ED[15], and in light of previously studied relationships of age-related variations of fullness and satisfaction with particular energy-dense diet models[16], in the current epidemiological study our aim was to examine gender-related

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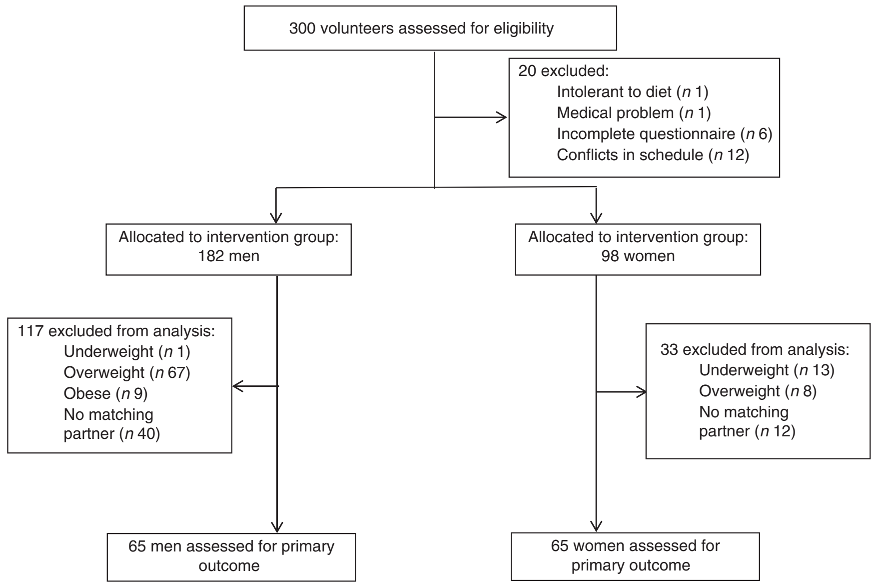

Fig. 1 Flow diagram of subject enrolment and completion of the study protocol among 300 volunteers assessed for eligibility in the present study. Halfway through the study, we excluded the following individuals: those unable to tolerate the test food items (*n* 1), those with poor health (*n* 1), those sending incomplete questionnaires (*n* 6) and those who were unexpectedly unavailable on the test dates (*n* 12). Then the gender groups were pair matched by age and BMI to eliminate the influence of factors except gender. Finally, a total of 130 individuals (sixty-five men and sixty-five women) with normal BMI (18·5 ≤ BMI (kg/m^2) < 25·0) were included in the study

differences in the sensory properties of food after consumption of lunches with different ED.

Prior research has indicated that women give greater importance to food choice behaviours than men[17,18]. In addition, salty food intake has been shown to lead to a decrease in the pleasantness of other savoury foods in previous studies of men[7,19], indicating that men would be satisfied with salty food. Therefore, we hypothesized that women would have greater sensitivities than men within sensory properties of food intake, and that men would prefer salty and fatty foods in their diets whereas women would have a stronger desire for sweetness. This study will further our understanding of human dietary behaviour to develop more effective gender-tailored diet models.

Materials and methods

Participants

Individuals living in Tokushima, Japan with sedentary clerical occupations and routine lifestyles who agreed to participate in the study were selected[16]. Halfway through the study, we excluded the following individuals: those unable to tolerate the test food items (*n* 1), those with poor health (*n* 1), those sending incomplete questionnaires (*n* 6) and those who were unexpectedly unavailable on the test dates (*n* 12). The gender groups were matched by age (within 10 years) and BMI (within 3 kg/m^2) to eliminate the influence of factors except gender. Finally, a total of 130 individuals (sixty-five men and sixty-five women) with normal BMI (18·5 ≤ BMI (kg/m^2) < 25·0) were included in the study (Fig. 1). The participants themselves reported their heights and weights according to the recorded data from their annual official medical examinations.

Each participant was provided with a detailed written explanation of the procedure of the study before we obtained informed consent. The study was conducted according to the guidelines laid down in the Declaration of Helsinki and all procedures involving human subjects were approved by the Ethics Committee of the Tokushima University Hospital. Participants were registered by the identification numbers to protect their information.

Study design

A randomized crossover design was used to investigate each test meal at lunchtime with a 1-week interval between testing sessions. Participants were asked to refrain from skipping meals, to refrain from drinking excessive alcohol and to maintain exercise at a consistent level before each scheduled session. During the study period, participants were randomly assigned into four groups for meals distribution. Group A and group B were administered meals following the sequence of lower to higher ED, and group C and group D were administered meals in the opposite manner. A packed test lunch was systematically provided on a specified day for six consecutive weeks (Table 1)[16]. The study was designed such that the majority of daily food and energy consumed was from the test foods, according to the 2010 Dietary Reference Intakes for Japanese[20].

Test meals

Six types of packed lunches were used as test meals with their basic composition and appearance remaining constant. An overview of the nutritional information of the

Table 1 Randomized crossover study design of six different types of test meals* in six experimental sessions

Week	Group A	Group B	Group C	Group D
1	Low-ED diet Control	Low-ED diet Hmeat	High-ED diet Hfat	High-ED diet HfatLveg
2	Medium-ED diet Lveg	Medium-ED diet MfatLveg	Medium-ED diet Lveg	Medium-ED diet MfatLveg
3	High-ED diet Hfat	High-ED diet HfatLveg	Low-ED diet Control	Low-ED diet Hmeat
4	Low-ED diet Hmeat	Low-ED diet Control	High-ED diet HfatLveg	High-ED diet Hfat
5	Medium-ED diet MfatLveg	Medium-ED diet Lveg	Medium-ED diet MfatLveg	Medium-ED diet Lveg
6	High-ED diet HfatLveg	High-ED diet Hfat	Low-ED diet Hmeat	Low-ED diet Control

Source: Zhou *et al.*[16]
ED, energy density.
*Control, control meal; Hmeat, high-meat/low-rice meal; MfatLveg, medium-fat/low-vegetable meal; Lveg, low-vegetable meal; Hfat, high-fat meal; HfatLveg, high-fat/low-vegetable meal.

test meals is provided in Table 2[16]. Rice was the staple food, and the main dishes were sautéed beef, steamed shiitake mushrooms with minced fish and mixed Japanese hotchpotch consisting of sweet potato, carrot, radish, dried shiitake mushrooms, bamboo shoot, lotus root and konjac. A green vegetable and kelp seaweed salad as well as tomato and broccoli jelly were also served as an integral part of each meal.

The test meals were varied by adding oil or by varying the volume of ingredients and the amounts (80 g or 240 g) of raw vegetable, which were consumed after cooking. Each participant was given 1 litre of chilled water to consume *ad libitum* throughout the test duration until dinner. Additional water was supplied if requested, but extra food and other drinks were forbidden. The six meals were provided on each test day with varied energy and ED as follows: (i) control meal (Control), energy 2092 kJ (500 kcal) and ED 3·1 kJ/g (0·8 kcal/g); (ii) high-meat/low-rice meal (Hmeat), energy 2146 kJ (513 kcal) and ED 3·1 kJ/g (0·7 kcal/g); (iii) low-vegetable meal (Lveg), energy 1788 kJ (427 kcal) and ED 4·1 kJ/g (1·0 kcal/g); (iv) medium-fat/low-vegetable meal (MfatLveg), energy 2175 kJ (520 kcal) and ED 5·0 kJ/g (1·2 kcal/g); (v) high-fat meal (Hfat), energy 3750 kJ (896 kcal) and ED 5·3 kJ/g (1·3 kcal/g); and (vi) high-fat/low-vegetable meal (HfatLveg), energy 3446 kJ (824 kcal) and ED 7·4 kJ/g (1·8 kcal/g)[16].

Comparison assessment approaches

The six meals, which differed in vegetable amounts and energy content, were primarily divided into two versions: (i) high-vegetable-content meals contained 240 g of vegetables, which included Control, Hmeat and Hfat meals; and (ii) low-vegetable-content meals contained 80 g of vegetables, which included Lveg, MfatLveg and HfatLveg meals. The Control, Hmeat and MfatLveg meals had low energy content with approximately 2092 kJ (500 kcal) but different nutritional composition in terms of the protein:fat:carbohydrate ratio, as the Control meal was converted into the Hmeat meal by decreasing the rice amount from 150 g to 100 g and increasing the raw beef amount of the sautéed beef entrée from 40 g to 80 g, and the MfatLveg meal was converted from the Control meal by altering the meat with a different part of beef and decreasing the vegetable amount from 240 g to 80 g. Moreover, the Control meal was converted into the Lveg meal by decreasing the vegetable amount from 240 g to 80 g and into the Hfat meal by adding oil and sauce. Likewise, the HfatLveg meal was converted from the Hfat meal by decreasing the vegetable amount by two-thirds. The vegetable amounts were weighed raw before cooking. Gender differences were compared on specific-sensory responses across the six meals.

Appetite and palatability desire ratings

Participants completed a series of 100 mm visual analogue scale (VAS) rating questionnaires[21] about appetite for fullness, satisfaction and prospective demand, and palatability desire for savoury, sweet, salty and fatty foods. For example, fullness and satisfaction were rated on the 100-mm lines preceded by the questions: 'How full do you feel right now?' and 'How much satisfaction do you feel right now?', and anchored on the left by 'not at all' and on the right by 'very much', respectively. Before the study, we explained the differences between satisfaction and fullness to the participants as follows: 'The big difference is that satisfaction provides more emphasis on a mood of satiation, for example, when we enjoy the favourite food'. Prospective demand and palatability desire for savoury, sweet, salty and fatty were rated on the 100-mm lines preceded by the questions: 'How much do you think you could eat right now?', 'How much savoury food do you think you could eat right now?', 'How much sweet food do you think you could eat right now?', 'How much salty food do you think you could eat right now?' and 'How much fatty food do you think you could eat right now?', and anchored on the left by 'nothing at all' and 'a large amount' on the right, respectively. The ratings were completed after looking at the appearance of test meals before intake and at 0·5, 1, 2, 3, 4 and 5 h after meals.

Table 2 Energy and macronutrient composition of the test meals*,†

Item	Control	Hmeat	MfatLveg	Lveg	Hfat	HfatLveg
Rice						
Amount (g)	150·0	100·0	150·0	150·0	150·0	150·0
Energy (kJ/kcal)	1054/252	703/168	1054/252	1054/252	1054/252	1054/252
ED (kJ per g/kcal per g)	7·0/1·7	7·0/1·7	7·0/1·7	7·0/1·7	7·0/1·7	7·0/1·7
Protein (g)	3·8	2·5	3·8	3·8	3·8	3·8
Fat (g)	0·5	0·3	0·5	0·5	0·5	0·5
Carbohydrate (g)	55·7	37·1	55·7	55·7	55·7	55·7
Vegetable amount (g)	0·0	0·0	0·0	0·0	0·0	0·0
Sautéed beef						
Amount (g)	79·0	158·0	79·0	79·0	89·0	89·0
Energy (kJ/kcal)	405/97	810/194	792/189	405/97	1177/281	1177/281
ED (kJ per g/kcal per g)	5·1/1·2	5·1/1·2	10·0/2·4	5·1/1·2	13·2/3·2	13·2/3·2
Protein (g)	8·7	17·4	6·0	8·7	6·0	6·0
Fat (g)	4·5	9·0	15·6	4·5	25·6	25·6
Carbohydrate (g)	4·7	9·4	4·5	4·7	4·5	4·5
Vegetable amount (g)	0·0	0·0	0·0	0·0	0·0	0·0
Steamed shiitake mushrooms with minced fish						
Amount (g)	49·0	49·0	49·0	49·0	53·0	53·0
Energy (kJ/kcal)	163/39	163/39	163/39	163/39	317/76	317/76
ED (kJ per g/kcal per g)	3·3/0·8	3·3/0·8	3·3/0·8	3·3/0·8	6·0/1·4	6·0/1·4
Protein (g)	5·0	5·0	5·0	5·0	5·0	5·0
Fat (g)	0·9	0·9	0·9	0·9	4·9	4·9
Carbohydrate (g)	3·2	3·2	3·2	3·2	3·2	3·2
Vegetable amount (g)	28·0	28·0	28·0	28·0	28·0	28·0
Mixed Japanese hotchpotch (sweet potato, etc.)‡						
Amount (g)	145·0	145·0	48·3	48·3	150·0	53·3
Energy (kJ/kcal)	265/63	265/63	87/21	87/21	457/109	280/67
ED (kJ per g/kcal per g)	1·8/0·4	1·8/0·4	1·8/0·4	1·8/0·4	3·1/0·7	5·3/1·3
Protein (g)	2·0	2·0	0·7	0·7	2·0	0·7
Fat (g)	1·2	1·2	0·4	0·4	6·2	5·4
Carbohydrate (g)	13·2	13·2	4·4	4·4	13·2	4·4
Vegetable amount (g)	78·0	78·0	26·0	26·0	78·0	26·0
Green vegetable and kelp seaweed salad						
Amount (g)	106·0	106·0	30·0	30·0	115·0	39·0
Energy (kJ/kcal)	44/11	44/11	13/3	13/3	391/94	360/86
ED (kJ per g/kcal per g)	0·4/0·1	0·4/0·1	0·4/0·1	0·4/0·1	3·4/0·8	9·2/2·2
Protein (g)	0·6	0·6	0·2	0·2	0·6	0·2
Fat (g)	0·1	0·1	0·0	0·0	9·1	9·0
Carbohydrate (g)	2·5	2·5	0·7	0·7	2·5	0·7
Vegetable amount (g)	58·0	58·0	14·0	14·0	58·0	14·0
Tomato and broccoli jelly						
Amount (g)	140·0	140·0	76·0	76·0	145·0	81·0
Energy (kJ/kcal)	161/39	161/39	66/16	66/16	354/85	259/62
ED (kJ per g/kcal per g)	1·2/0·3	1·2/0·3	0·9/0·2	0·9/0·2	2·4/0·6	3·2/0·8
Protein (g)	5·0	5·0	2·9	2·9	5·0	2·9
Fat (g)	0·4	0·4	0·1	0·1	5·4	5·1
Carbohydrate (g)	5·5	5·5	1·3	1·3	5·5	1·3
Vegetable amount (g)	76·0	76·0	12·0	12·0	76·0	12·0
Total						
Weight (g)	669·0	698·0	432·3	432·3	702·0	465·3
Energy (kJ/kcal)	2092/500	2146/513	2175/520	1788/427	3750/896	3446/824
ED (kJ per g/kcal per g)	3·1/0·8	3·1/0·7	5·0/1·2	4·1/1·0	5·3/1·3	7·4/1·8
Protein						
(g)	25·0	32·4	18·4	21·1	22·3	18·4
%	20·0	25·3	14·2	19·8	10·0	9·0
Fat						
(g)	7·5	11·8	17·4	6·3	51·6	50·4
%	13·5	20·8	30·2	13·3	51·8	55·1
Carbohydrate						
(g)	84·7	70·8	69·8	69·9	84·5	69·8
%	66·5	53·9	55·6	66·9	38·2	35·9
Vegetable amount (g)	240·0	240·0	80·0	80·0	240·0	80·0
Dietary fibres (g)	7·6	7·5	2·9	2·9	7·6	2·9
Salt (g)	2·3	2·9	1·8	1·8	2·3	1·8

Source: Zhou *et al.*[16].
ED, energy density.
*Six versions of each meal were served. All values were calculated on the basis of test meals.
†Control, control meal; Hmeat, high-meat/low-rice meal; MfatLveg, medium-fat/low-vegetable meal; Lveg, low-vegetable meal; Hfat, high-fat meal; HfatLveg, high-fat/low-vegetable meal.
‡Mixed Japanese hotchpotch, a traditional Japanese dish similar to a Western-style stew or hot pot with all ingredients simmered in one pot.

Data analysis

To evaluate the gender differences in specific-sensory responses, we calculated the area under the curve (AUC) of VAS ratings for gender-related sensory properties with different meals. Unpaired *t* tests were used to assess gender differences on sensory properties by evaluating VAS ratings and AUC of VAS ratings for the six meals. ANOVA with repeated measures and Bonferroni *post hoc* tests evaluated the ratings of sensations with test meals from 0 h to 5 h after meals and the differences of sensation ratings among test meals in each group.

In our preliminary analysis, 15 mm VAS difference with 20 mm SD was expected, i.e. effect size of 0·75. For example, ensuring a two-tailed α error of 0·05 and β error of 0·20, the required sample size is twenty-nine participants per comparison group.

All statistical analyses were performed using statistical software package SPSS version 16·0 (2007). The results are reported as means with their standard errors and were considered significant at $P<0·05$.

Results

Participants

Participant characteristics, including mean age, weight, height and BMI, are shown in Table 3. The two gender groups included sixty-five men and sixty-five women who were matched by age and BMI to eliminate these influence factors. Thus, there were no significant differences in BMI and age between the gender groups.

Comparisons of gender differences on sensory properties with test meals

Ratings of sensory properties between genders with test meals are shown in the online supplementary material (Supplemental Table 1 and Supplemental text) and Fig. 2. Overall, women had a significantly stronger desire for sweetness than men, whereas men had stronger desires for salty and fatty foods than women, after meals.

From 3 h after the Lveg meal, the desire for savoury food was significantly higher in women than in men ($P<0·05$). AUC of VAS ratings for savoury desire were significantly higher in women than in men with the Lveg meal ($P=0·033$). AUC for prospective demand were significantly lower in women than in men with the Control meal ($P=0·006$), and AUC of VAS ratings for fullness were significantly higher in women than in men with the Control meal ($P=0·015$).

Similarly, VAS ratings of sweetness desire after meals were significantly higher in women than in men ($P<0·05$) except with the Control meal, which showed that VAS ratings of sweetness desire in women at 0·5–2 h after meals were significantly lower than those before meals ($P<0·01$). In contrast, sweetness desire with the low-ED Hmeat diet was stronger in women than in men from 3 h after meals ($P<0·05$). Although ratings of fullness ($P<0·001$) and satisfaction ($P=0·014$) were also significantly higher in women than in men after intake of the Hfat meal at 0·5 h, sweetness desire was stronger in women than in men from 4 h after meals ($P<0·05$). Ratings of sweetness desire with the Lveg, MfatLveg and HfatLveg meals were significantly higher in women than in men from 2 h ($P=0·043$), 4 h ($P=0·019$) and 5 h ($P=0·021$) after meals, respectively. Moreover, AUC of VAS ratings for sweetness desire were significantly higher in women than in men with the Hmeat ($P=0·024$) and Lveg ($P=0·008$) meals.

Ratings of salty and fatty desire were significantly lower in women than in men with high-vegetable-content meals at 0·5–3 h after meals, especially with the Control meal, which showed significance at 0·5–5 h after meals ($P<0·05$). In addition, AUC of VAS ratings for the desire for salty food were significantly higher in men than in women ($P<0·05$), except with the Lveg meal, and AUC of VAS ratings for the desire for fatty food were significantly higher in men than in women regardless of meals ($P<0·05$).

Sensory response differences with test meals in each gender group

As shown in Figs 3 and 4, meals with higher vegetables provided greater fullness and satisfaction regardless of gender, although response to meals changed within a smaller range for men than for women.

Sensory response in men

Appetite ratings for fullness and satisfaction were significantly higher with the Hfat meal than with the HfatLveg meal at 0·5 h ($P=0·001$) and 1 h ($P=0·019$) after meals. Ratings for prospective demand were significantly lower

Table 3 Characteristics of participants in the randomized crossover study, Tokushima, Japan*

	Total (*n* 130)		Men (*n* 65)		Women (*n* 65)	
Characteristic	Mean	SE	Mean	SE	Mean	SE
Age (years)	39·9	0·8	40·1	1·1	39·6	1·1
Height (cm)	165·1	0·8	171·6	0·7	158·6	0·7
Weight (kg)	58·3	0·7	63·5	0·8	53·1	0·6
BMI (kg/m^2)	21·3	0·1	21·5	0·2	21·1	0·2

*There were no significant differences in BMI and age between men and women.

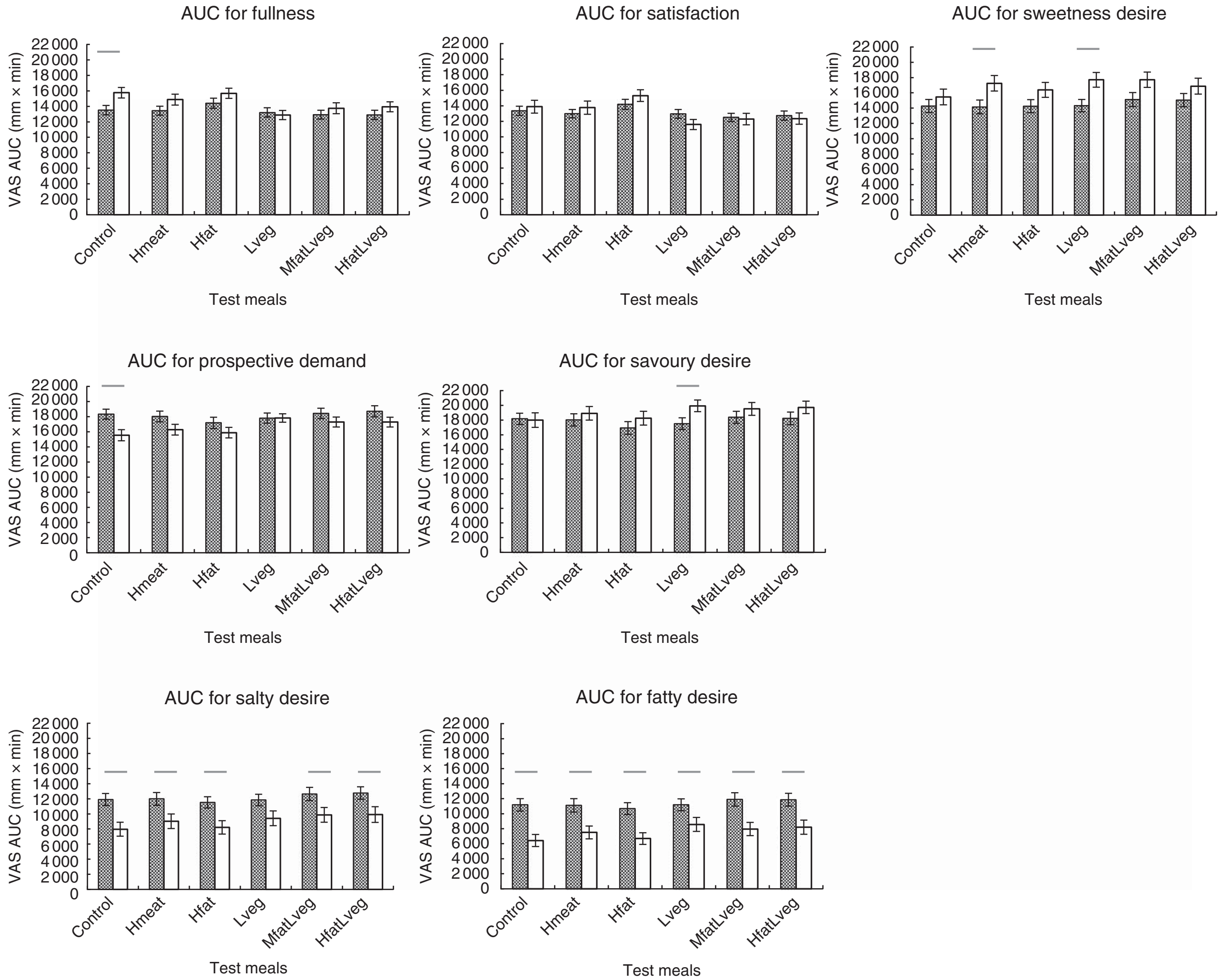

Fig. 2 Areas under the curve (AUC) of visual analogue scale (VAS) ratings (means with their standard errors represented by vertical bars) for sensory properties after consumption of different test meals, by gender, in a randomized crossover study of sixty-five men (▩) and sixty-five women (□), matched by age and BMI, Tokushima, Japan. AUC were calculated over the entire period from 0 to 5 h after meals. Differences ($P<0·05$) between genders were assessed by using unpaired *t* tests and are represented by the horizontal lines. Control, control meal; Hmeat, high-meat/low-rice meal; MfatLveg, medium-fat/low-vegetable meal; Lveg, low-vegetable meal; Hfat, high-fat meal; HfatLveg, high-fat/low-vegetable meal

with the Hfat meal than with the HfatLveg meal at 1 h ($P=0·008$) and 2 h ($P=0·023$) after meals. There were no significant differences for palatability desire except for savoury ($P=0·044$) and fatty foods ($P=0·026$), which were significantly lower with the Hfat meal than with the HfatLveg meal at 1 h after meals.

Sensory response in women

Appetite ratings for fullness were significantly higher with the Control meal than with the MfatLveg meal or the HfatLveg meal at 0·5 h and 1 h after meals ($P<0·01$). Ratings for satisfaction were significantly higher with the Control meal than with the MfatLveg meal ($P=0·008$) or the HfatLveg meal ($P=0·007$) at 0·5 h after meals. Ratings for savoury and fatty food desire were significantly lower with the Control meal than with the Lveg meal at 1 h ($P=0·044$) and 3 h ($P=0·010$) after meals, respectively. Sweetness desire ratings were significantly lower with the Control meal than with the MfatLveg meal at 1 h after meals ($P=0·025$).

Discussion

The present study is the first to examine the effects of dietary ED on a variety of sensory properties of food with typical Japanese diets between genders using a large sample size and a population-based prospective design.

The results from the study demonstrate gender differences in sensory properties of food after different meals. The study had three main findings: (i) meals with higher vegetables provided greater fullness and satisfaction

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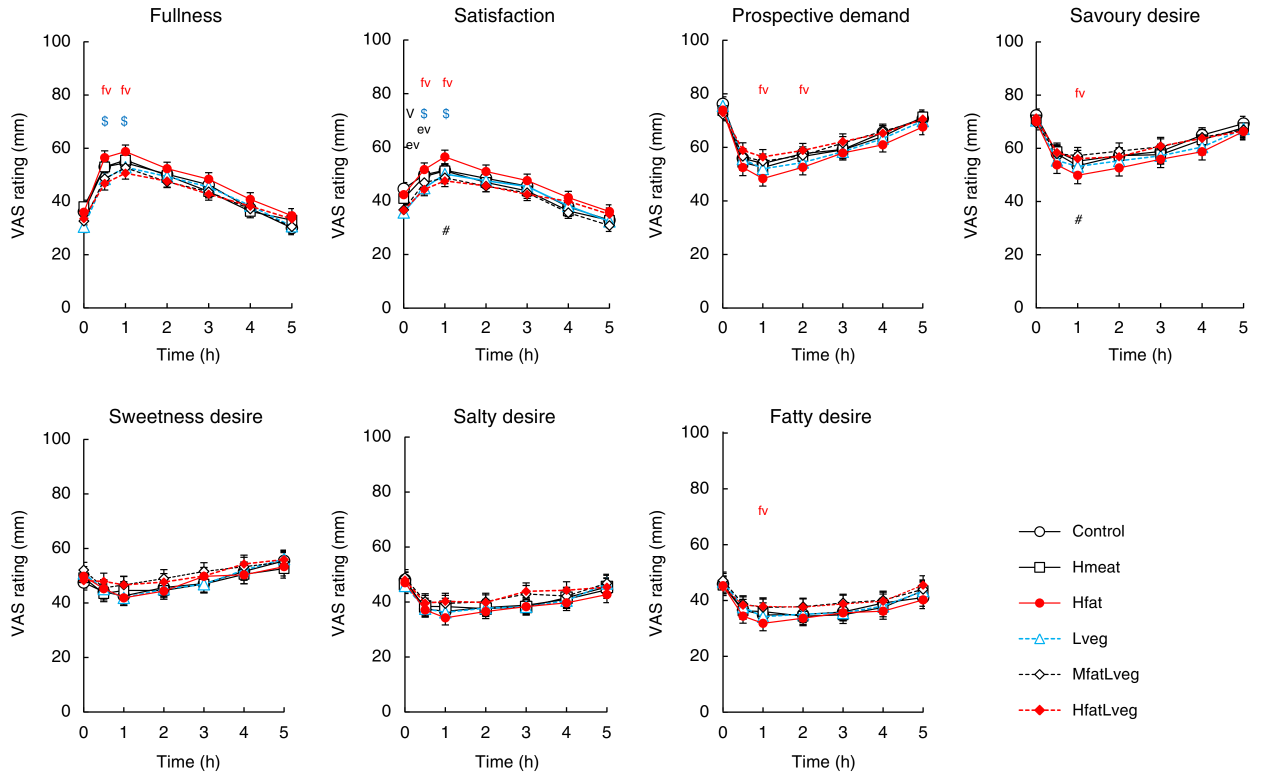

Fig. 3 Visual analogue scale (VAS) ratings (means with their standard errors represented by vertical bars) for sensory properties after consumption of different test meals in sixty-five men participating in a randomized crossover study, Tokushima, Japan. Differences ($P < 0{\cdot}05$) among the meals at each time point were assessed by using repeated-measures ANOVA followed by Bonferroni *post hoc* tests: V, Control *v.* MfatLveg; ev, Control *v.* Lveg; fv, Hfat *v.* HfatLveg; $, Lveg *v.* Hfat; #, MfatLveg *v.* Hfat. Control, control meal; Hmeat, high-meat/low-rice meal; MfatLveg, medium-fat/low-vegetable meal; Lveg, low-vegetable meal; Hfat, high-fat meal; HfatLveg, high-fat/low-vegetable meal

regardless of gender; (ii) although responses to meals changed within a smaller range for men than for women, men had stronger desires for salty and fatty food than women after meals; and (iii) women had stronger desire for sweetness than did men, except after the Control meal with 150 g of rice, and a lower rice intake in the low-ED diet also stimulated sweetness desire in women more than in men.

Sensory properties of food, including appetite factors and palatability desire, play major roles in the selection of diets, which influences food intake. Fullness is the feeling that persists after eating to suppress further food consumption, whereas satisfaction emphasizes a mood that leads to the termination of eating. Both fullness and satisfaction influence the prospective demand, which regulates appetite[22]. Simultaneously, savoury, sweet, salty and fatty elements are the major constituents of palatability in a daily diet.

ED appears to be a major dietary factor influencing food intake[23,24]. Evidence in our previous study also suggests that low-ED diets promote fullness and satisfaction and may help to control weight[16]. As predicted, sensory-specific responses in the present study changed within a smaller range in men than in women probably due to women's greater concern about diet. One possibility is that women are not only more concerned about their health, but are also more likely to translate these concerns into the selection of their daily diets[12,17,18].

Taste preference which reflects palatability of foods is also associated with daily intake[25–27]. Researchers in one study speculated that compared with men, women have better gustatory responses with the sweet taste and worse gustatory responses with the salt taste[28], which is also supported in the current study. Salt taste, as an essential element during cooking, can balance flavour in food. Salt preference is mostly influenced by dietary restraint[29] and exercise[30]. Additionally, habitual intake is another factor affecting salt preference[31,32]. In the present study, men showed stronger desire for salty and fatty foods than women after intake, whereas women showed stronger desire for sweet food than men, probably due to the taste differences between genders[28]. A previous study found that gene variations in the presence of receptor proteins could play a role related to the differences in fat preferences between genders[26]. However, compared with sweet and fat appetite acquired from early childhood[33], salt preference is more complex and less understood[34]. Moreover, sweet taste in foods, which is considered to be an important sensory property of food for nutritive energy, has an undeniable sensory appeal along with the

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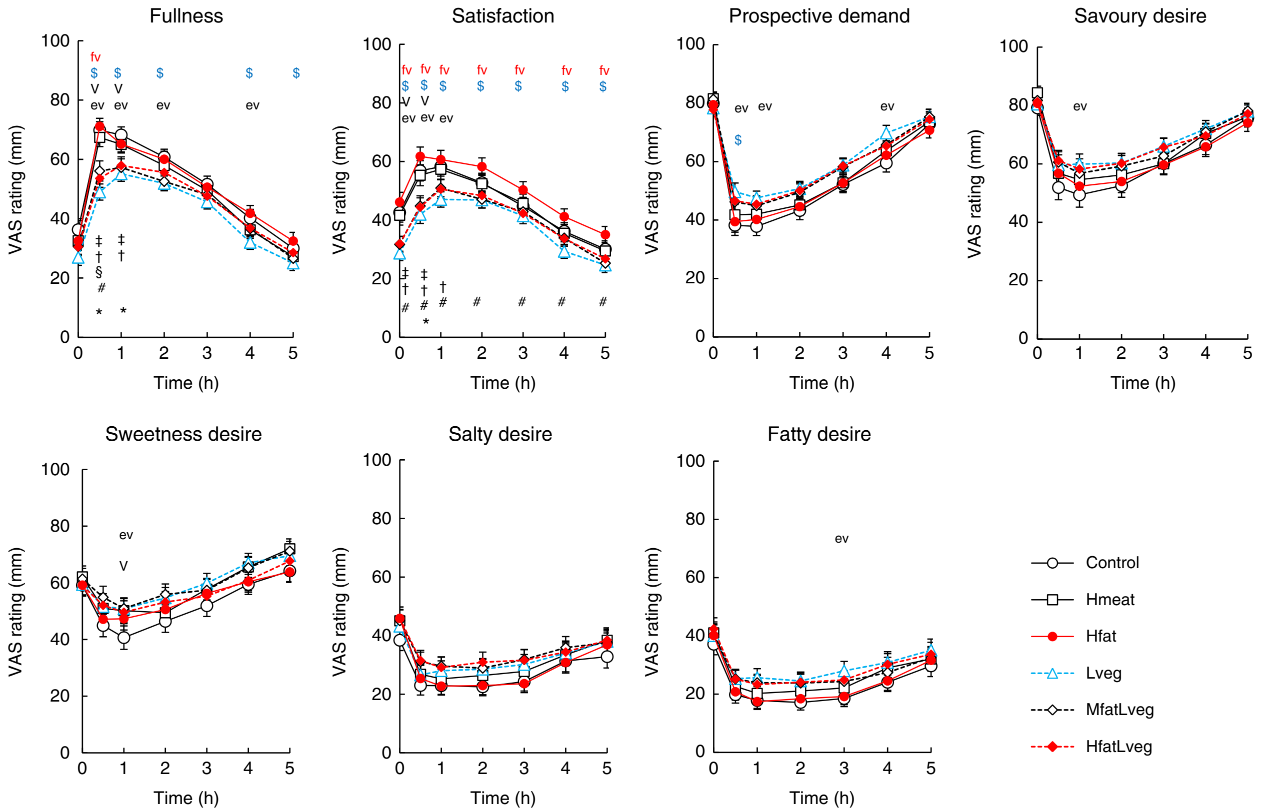

Fig. 4 Visual analogue scale (VAS) ratings (means with their standard errors represented by vertical bars) for sensory properties after consumption of different test meals in sixty-five women participating in a randomized crossover study, Tokushima, Japan. Differences ($P < 0·05$) among the meals at each time point were assessed by using repeated-measures ANOVA followed by Bonferroni *post hoc* tests: V, Control *v.* MfatLveg; ev, Control *v.* Lveg; *, Control *v.* HfatLveg; fv, Hfat *v.* HfatLveg; $, Lveg *v.* Hfat; ‡, Hmeat *v.* MfatLveg; †, Hmeat *v.* Lveg; §, Hmeat *v.* HfatLveg; #, MfatLveg *v.* Hfat. Control, control meal; Hmeat, high-meat/low-rice meal; MfatLveg, medium-fat/low-vegetable meal; Lveg, low-vegetable meal; Hfat, high-fat meal; HfatLveg, high-fat/low-vegetable meal

fatty taste[35]. Earlier findings indicated that adding flavour and improving food texture with fat could increase the palatability of meals[36,37]. On the other hand, vegetables are important components of the diet that can help individuals reach a sufficient fullness without decreasing food volume due to the lower ED[5,16].

In the low-vegetable-content meals, VAS data show that women had stronger desire for sweetness than men after meals, especially with the Lveg meal, which stimulated higher sweetness desire in women than in men from 2 h after the meal. However, with increased fat content in the MfatLveg meal, the sweetness desire was higher in women than in men starting from 4 h after meals. With the additional increase in fat content by the addition of oil in the HfatLveg meal, no significant differences between genders in the sweetness desire were shown until 5 h after the meal, suggesting that fat plays an important role without sufficient vegetables in a practical diet. Notably, in the high-vegetable-content meals, no significant differences were observed between genders after intake of the Control meal, even with a low energy content of 2092 kJ (500 kcal). Interestingly, when the meal was changed to the Hfat meal with an increased fat content by adding oil, sweetness desire was higher in women than in men from 4 h after the meal.

Fat, as an important factor increasing palatability in a meal, enhances sensitivity to satisfaction signals by elevating leptin and insulin signalling in the central nervous system[38,39]. The pleasurable aspects of fat consumption provide a hedonic preference for food due to the rewarding and reinforcing properties of some dietary fats[40,41]. The current study reflects that fat might suppress sweetness desire in a diet with vegetable content as low as 80 g, whereas in a diet with sufficient vegetable content such as 240 g, increased fat content might stimulate the redundant sweetness desire. This stimulation is probably due to initiating a vicious cycle from the increased palatability of the diet. A previous study reported that the increased fat content that promotes the sensory properties of the diet causes insulin/leptin resistance, resulting in more food consumption[42].

In addition, in the low-ED Hmeat diet containing 240 g of vegetables, higher sweetness desire was stimulated in women more than in men from 3 h after the meal, mainly due to the lower (100 g) rice intake. Rice is a major dietary staple, forms the basis of the dietary pattern in most Asian countries and is traditionally consumed with other dishes[43]. The low-ED Control diet included 150 g of rice, providing sufficient carbohydrate, compared with the high-meat/low-rice meal. However, it resulted in no significant differences for sweetness desire between genders. Taken together, the results indicate that sweetness desire, especially for women, is also stimulated by decreasing rice intake in the low-ED diet model.

The strengths of the present study are that it elucidates sensory property differences between genders and also explores practical dietary advice of low-ED diet models. The test meals provide the flexibility to make a diet that is highly satiating without increased fat content or additional oil by increasing vegetables, thus controlling energy intake. Consumption of 240 g of vegetables and 150 g of rice in a 2092 kJ (500 kcal) lunch could be sufficiently satisfying and might potentially lower the prevalence of obesity because no additional oil was used in the low-ED model and there was no redundant sweetness desire after intake. One of the limitations of the study is the single staple food. Results with a Western diet model with bread as the staple food might be different. Another limitation is that the participants in the current analysis were all clerical staff with normal BMI and the patterning of gender differences may be different in other populations who have varied activities or BMI. More extensive research is needed to address these points.

Conclusion

The present study suggests that increasing vegetable intake in a diet is effective to enhance fullness and satisfaction regardless of gender. Men had stronger desire for salty and fatty foods, whereas women preferred sweetness after meals. Sweetness desire, especially for women, was stimulated by high fat content, even with high vegetable intake. In other words, fat appears to perform a redundant role to stimulate sweetness desire in a practical diet with high vegetable intake (e.g. 240 g). Furthermore, low rice intake in low-ED diets also stimulated sweetness desire in women more than in men. Our results provide useful insights into the role of sensory properties on food intake across genders, although more studies are needed.

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Supplementary material

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