British Journal of Nutrition (2009), **102**, 470–477
doi:10.1017/S0007114508201960

Increased portion size leads to a sustained increase in energy intake over 4 d in normal-weight and overweight men and women

Mary T. Kelly[1], Julie M. W. Wallace[1], Paula J. Robson[2], Kirsten L. Rennie[1,3], Robert W. Welch[1], Mary P. Hannon-Fletcher[1], Sarah Brennan[1], Adrian Fletcher[1] and M. B. E. Livingstone[1]*

[1]*Northern Ireland Centre for Food and Health (NICHE), University of Ulster, Cromore Road, Coleraine BT52 1SA, UK*
[2]*School of Public Health, University of Alberta, Canada*
[3]*School of Health and Emergency Services, University of Hertfordshire, Hatfield AL10 9AB, UK*

(Received 10 July 2008 – Revised 26 November 2008 – Accepted 27 November 2008 – First published online 16 February 2009)

Large food portions may be facilitating excess energy intake (EI) and adiposity among adults. The present study aimed to assess the extent to which EI and amounts of foods consumed are influenced by the availability of different-sized food portions. A randomised within-subject cross-over, fully residential design was used, where forty-three (twenty-one men and twenty-two women) normal-weight and overweight adults were randomly allocated to two separate 4 d periods where they were presented with either 'standard' or 'large' food portions of the same foods and beverages. The main outcome measures were the amount of food (g) and EI (MJ) consumed throughout each study period. Mean EI over 4 d was significantly higher on the large portion condition compared with the standard condition in the total group (59·1 (SD 6·6) *v.* 52·2 (SD 14·3) MJ; $P=0{\cdot}020$); men and women increased their EI by 17 % (10 (SD 6·5) MJ; $P<0{\cdot}001$) and 10 % (4 (SD 6·5) MJ; $P=0{\cdot}005$) respectively when served the large food portions relative to the standard food portions. The increased intakes were sustained over the 4 d in the large portion condition with little evidence of down-regulation of EI and food intake being made by subjects. Increased food portion size resulted in significant and sustained increases in EI in men and women over 4 d under fully residential conditions. The availability and consumption of larger portions of food may be a significant factor contributing to excess EI and adiposity.

Appetite: Energy intake: Obesity: Portion size: Weight management: Adults

The burgeoning rates of obesity in genetically stable populations such as in Europe and North America suggest that an increasingly obesogenic environment is the major driving force behind this epidemic[1]. Fostering the delicate balance between energy intake (EI) and energy expenditure to maintain a healthy body weight is now exceedingly difficult for many individuals. In the past few decades several key environmental and cultural factors have converged to increase the probability of over-eating in the face of reduced energy needs.

One environmental factor which has become the focus of attention is that of food portion size, which has been increasing steadily over the past two decades in parallel with the rise in overweight and obesity[2,3]. Studies have demonstrated that portions of food sold in supermarkets, fast food establishments and restaurants have steadily increased since the mid 1980s[3,4], a trend that has been most apparent and best documented in the USA. Consequently, it is hypothesised that increasing portion sizes of food may be undermining normal appetite control and inciting over-eating.

One possible reason for over-eating is that consumers tend to eat what they are served[5], even if it is an inappropriate amount for their energy needs, and consequently may not compensate for this overconsumption at subsequent eating occasions. Indeed, it may be the case that the availability of larger food portions may have a greater impact on food consumption than physiological satiety cues.

However, despite pervasive commercial trends towards large food portions, there is surprisingly little hard evidence that these are causally linked to excess EI or indeed obesity. Thus, while the proposition that large portion sizes promote overconsumption is intuitively logical, to date the empirical studies, while supportive[6–13], have been specific to the US context and have been conducted under semi-controlled conditions; the extent to which these findings would be relevant to the UK population is unknown at present.

The present study aimed to determine the extent to which the availability of different-sized predefined and pre-packed food portions would affect the amounts of food consumed, EI and self-perceived appetite sensations in normal-weight

Abbreviations: DEBQ, Dutch Eating Behaviour Questionnaire; ED, energy density; EI, energy intake.

* **Corresponding author:** M. B. E. Livingstone, fax +44 28 7032 3023, email mbe.livingstone@ulster.ac.uk

and overweight adults over four consecutive days under fully residential conditions.

Methods

Experimental design

The study used a randomised within-subject cross-over design. Each subject was studied under two experimental conditions, each lasting for four consecutive days with a 3-week interval between each study period. For the duration of each study period, subjects were fully residential in the Human Intervention Studies Unit, which consists of ten en-suite bedrooms, a volunteers' living room, dining room and diet preparation kitchen. Approximately eight subjects were residential during each study period and during the day each subject was free to follow their normal routine in the University but returned to the Human Intervention Studies Unit for all meals and snacks, and did not leave the University campus while under study conditions. Subjects were sedentary during each study period and were asked to refrain from active recreational pursuits. Free association was allowed between subjects.

The order of presenting the two portion conditions was randomised across subjects. During one of the 4 d periods subjects were served 'standard' portions of all foods and beverages; for the other 4 d period, subjects were served 'large' portions of all foods and beverages. The portion sizes selected were driven by commercially available units, namely the smallest pre-portioned units available (standard portion size), and units of the same foods which are designed to serve two or more people (large portion size). Differing sizes of serving dishes were used for the two portion treatments so that visually the portions would not seem different to the subjects. During the first 4 d study period, each subject selected foods from a menu of breakfast, lunch, dinner and dessert items. For the second study period, subjects were provided with identical foods to those chosen during the first study period, the only change being the adjustment of portion size.

Ethical approval for the present study was granted by the Office for Research Ethics Committee for Northern Ireland (ORECNI) and subjects gave written informed consent before commencement of the study. To ensure that subjects remained blind as to the true nature of the study, the consent form stated that the purpose of the study was to investigate the effect of mood on food choice. Each subject was financially compensated for their time.

Subject recruitment

Subjects were recruited by advertisements throughout the University. Individuals aged 18–65 years, who expressed interest in the study, were interviewed to ensure their eligibility for participation. Exclusion criteria were: smokers; vegetarians; those taking prescription medications or any drugs that might interfere with normal food intake; food allergies or dietary restrictions; chronic disease; BMI $< 18{\cdot}5$ or $> 30\,kg/m^2$; unwilling to participate in a fully residential study. Data from a previous portion-size study[7] suggested that the within-subject SD for the amount of food consumed in one meal is unlikely to exceed 20 g. As a conservative estimate, because the consumption from several meals was compared between interventions, a within-subject SD of 40 g was assumed. The minimum difference of interest was 65 g. Given these assumptions, it was anticipated that forty subjects would be adequate to provide 90 % power. Before commencement of the study, menus were presented to eligible subjects to ensure the acceptability of the food choices on offer.

Menus and portion sizes

All food items were either served as a 'standard' or 'large' portion, depending on the treatment condition. The weights of foods, beverages and snack items on offer to the subjects on both study conditions are presented in Appendix 1. The variation in the magnitude of the increase in food portion size was based on and similar to that which is commercially available. Regardless of the combination of meal choices made by the subjects, the foods served at meals on the standard portion condition met the estimated energy requirements for sedentary populations (calculated as BMR $\times$ 1·4)[14].

Data collection

Subjects were asked to refrain from eating and drinking from 21.00 hours on the evening prior to each study period, and attended the Human Intervention Studies Unit at 08.00 hours on the first day (Monday) of both study periods, when height and weight were recorded, after voiding, using standardised procedures. Weight was again recorded after voiding, before breakfast, on the final morning (Friday) of each study period. Body weight was measured to the nearest 0·1 kg and height was measured in duplicate using a stadiometer (CMS Weighing Equipment, London, UK). At the outset of the study each subject completed the Dutch Eating Behaviour Questionnaire (DEBQ)[15]. On each of the 4 d of the study periods, subjects ate breakfast, lunch and dinner at specified times in the dining room. In addition, each subject was assigned a personal refrigerator and cupboard that contained a variety of snack items which could be eaten *ad libitum* throughout the day. Subjects were instructed to consume only the foods and beverages that were provided for them in the Human Intervention Studies Unit and not to share food items with others. Subjects were advised that they could consume as much of the foods and beverages as desired on both the standard and large portion conditions and were aware that more food was always available on request. Each meal was made up of defined portions that were served in individual dishes, for example, chicken curry (one dish) with rice (one dish). From these individual dishes, the subject served themselves the amount of food that they wanted. All foods, beverages and snacks were accurately and covertly weighed before and after each eating occasion by the researchers to determine the amount consumed (to the nearest g). Energy and macronutrient intakes of meals, snacks and beverages were analysed using the dietary analysis program WISP (version 3; Tinuviel Software, Warrington, UK). Subjects completed visual analogue scales immediately before and after each meal to rate their feelings of hunger, fullness, desire to eat and prospective consumption[16]. For example, subjects responded to the question 'How hungry do you feel?' by

marking a 100 mm line that was anchored on the left by 'Not hungry at all' and on the right by 'As hungry as I have ever felt'. At the end of each 4 d study period subjects completed an end-of-study questionnaire designed to rate their perceptions of the portion sizes offered. In order to avoid drawing the subjects' attention to these questions, the food portion questions were embedded in a range of more general questions about mood and surroundings.

Statistical analysis

All analyses were performed using SPSS (version 11.5; SPSS, Inc., Chicago, IL, USA). Data were assessed for normality using Shapiro–Wilk tests. Differences between men and women in baseline characteristics, DEBQ scores, EI, percentage EI and weight change were assessed by using *t* tests and weight status category by χ^2 tests. Paired *t* tests were used to determine whether differences in EI and bodyweight changes were apparent between the two portion size conditions in the whole group and stratified by sex. General linear models with repeated measures and Bonferroni *post hoc* comparisons were used with the main outcomes being EI (MJ) and the amount of food consumed (g). The between-subject factor was portion condition. Covariates in the main model were sex, age (years), BMI (kg/m^2) and treatment order (1, 2). Secondary outcomes were dietary energy density (ED; kJ/g), subject's ratings of hunger, fullness, desire to eat and prospective consumption. EI by meal (breakfast, lunch, dinner and snacks) was examined within each day and over the 4 d. Regression analyses were used to determine the relative influence of experimental and subject characteristics on percentage increase in EI from the standard to the large portion condition and on weight change during the large portion condition. Results were considered significant at $P<0{\cdot}05$.

Results

Subjects

Forty-four subjects (twenty-two men and twenty-two women) were enrolled on the study. One subject did not comply with the study protocol and was excluded. The characteristics, anthropometric measures and DEBQ scores of the forty-three subjects (twenty-one men and twenty-two women) who completed the study are presented in Table 1. Women were significantly older, shorter, lighter and had lower BMI than men ($P<0{\cdot}05$ in all cases). Results from the DEBQ showed that both men and women scored highest on the external eating category compared with the dietary restraint and emotional eating categories. Women scored significantly higher than men in the dietary restraint ($P=0{\cdot}018$) and emotional eating ($P=0{\cdot}001$) categories. However, no difference between women and men in the external eating category was observed ($P=0{\cdot}875$).

Food intakes

Total EI over the 4 d was significantly increased in the large portion size condition compared with the standard portion size condition in the whole group, with an additional 14 % (7 MJ; $P=0{\cdot}020$) energy consumed. On a daily basis, men increased their EI by an average 2·4 (SD 1·6) MJ ($P=0{\cdot}001$) and women increased intakes by 1·1 (SD 1·6) MJ ($P=0{\cdot}005$); over the 4 d, this resulted in a 17 % (10 MJ) and 10 % (4 MJ) increase in EI respectively. Total food weight consumed (kg) over the 4 d also significantly increased in the large portion condition compared with the standard portion condition (17·2 (SD 4·4) *v.* 15·4 (SD 3·6) kg, 14 *v.* 20 % co-efficient of variance; $P=0{\cdot}035$). Mean daily EI did not significantly differ across the study days on either the standard portion (men 14·7 MJ; women 11·5 MJ) or the large portion (men 17·1 MJ; women 12·6 MJ) conditions; indicating that no compensation was made in either condition for the energy and food consumed during the 4 d periods (Fig. 1).

Average EI at each meal on each study day for men and women on both study conditions is shown in Fig. 2.

Table 1. Description of subjects and Dutch Eating Behaviour Scores (Mean values and standard deviations)

	Men (*n* 21)		Women (*n* 22)	
Characteristic	Mean	SD	Mean	SD
Age (years)	29·7	4·6	31·7*	9·5
Normal weight	28·9	4·1	29·9	7·9
Overweight	30·3	5·1	35·4*	12·0
Height (m)	1·7	0·07	1·6*	0·05
Normal weight	1·8	0·08	1·7*	0·05
Overweight	1·8	0·07	1·6*	0·05
Weight (kg)	79·3	11·7	64·3*	8·9
Normal weight	69·8	9·3	59·5*	4·4
Overweight	86·4	7·4	74·7*	7·2
BMI (kg/m^2)†	25·3	2·9	23·7*	3·3
Normal weight (%)‡	42·9		68·2	
Overweight (%)‡	57·1		31·8	
Dietary restrained score§	2·0	0·6	2·5*	0·7
Emotional eating score§	1·7	0·6	2·5*	0·8
External eating score§	3·3	0·6	3·2	0·5

* Mean value was significantly different from that for men ($P<0{\cdot}05$).
† Normal weight, BMI 18·5–24·9 kg/m^2; overweight, BMI 25·0–29·9 kg/m^2.
‡ Compared using χ^2 tests.
§ Scores from the Dutch Eating Behaviour Questionnaire[15].

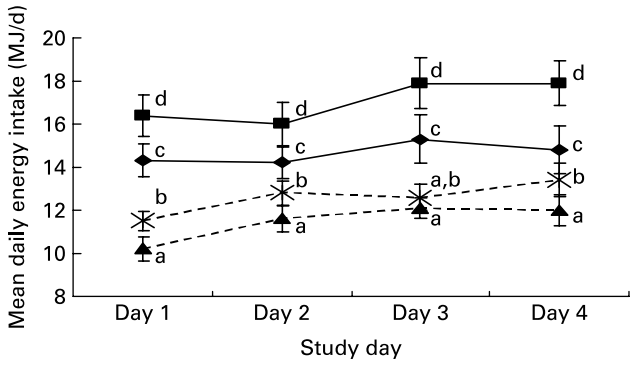

Fig. 1. Energy intakes for men (large portion (LP) –■–; standard portion (SP) –◆–) and women (LP – × –; SP –▲–) for each study day on both portion conditions. Data were analysed using the general linear model with repeated measures with Bonferroni corrections, adjusted for age, BMI and treatment order. Values are means, with their standard errors represented by vertical bars. ^{a,b,c,d} Mean values within and between study days with unlike letters were significantly different ($P<0{\cdot}05$).

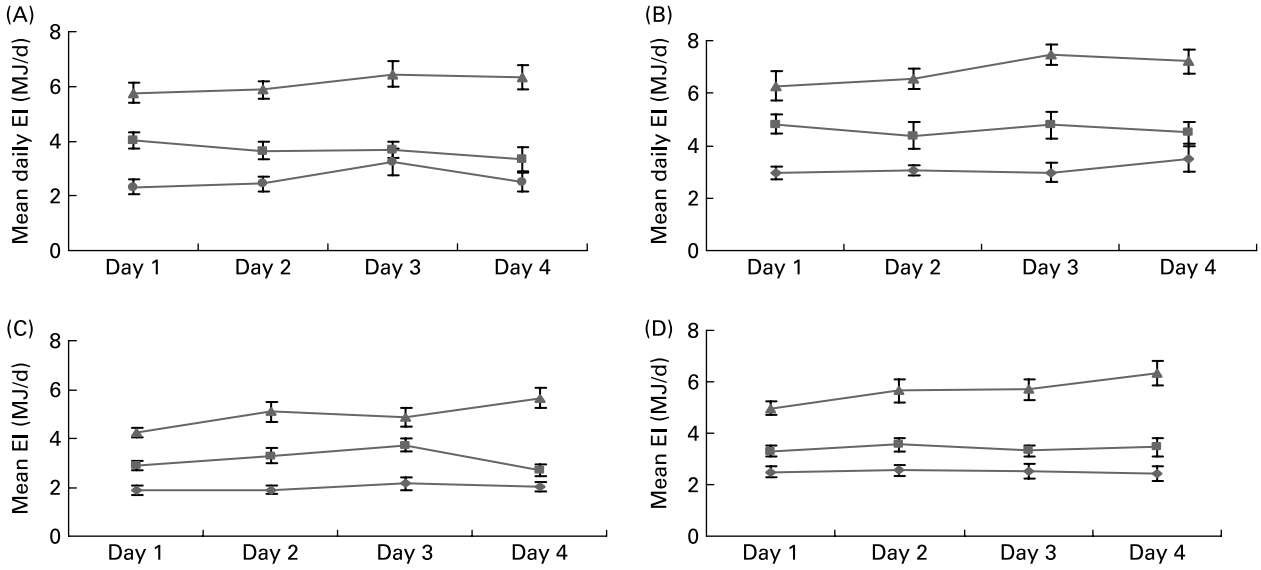

Fig. 2. Daily energy intakes (EI) at each meal (breakfast ▲; lunch ■; dinner ●) on each study day. (A) EI for men (*n* 21) for the standard portion study condition. (B) EI for men (*n* 21) for the large portion study condition. (C) EI for women (*n* 22) for the standard portion study condition. (D) EI for women (*n* 22) for the large portion study condition. Data were analysed using the general linear model with repeated measures with Bonferroni *post hoc* tests, adjusted for age, BMI and treatment order. There was an increase in EI at each meal occasion in the whole group between portion treatments (breakfast, lunch and dinner; $P<0{\cdot}001$). Between days there were no differences in EI at meals in either study condition for both men and women.

The consumption of the larger portion sizes led to a consistent increase in EI at each meal occasion in the whole group (breakfast, lunch and dinner; all $P=0{\cdot}001$). On a daily basis, there were no differences in EI at meals between the 4 d in either study condition in men or women. Thus on a meal-by-meal basis, there was no observed adjustment of EI over the 4 d period for the overconsumption of energy. When expressed as percentage of EI, the proportion of daily energy obtained from meals was greater in both men and women in the large portion condition ($P<0{\cdot}001$). Interestingly, percentage energy from snacks was greater on the standard portion condition relative to the large portion condition in both men and women (24 and 38 % increase in snack energy respectively) ($P<0{\cdot}001$). Men significantly increased their percentage energy from fat (37·3 (SD 3·7) *v.* 39·2 (SD 3·8); $P<0{\cdot}001$) and decreased percentage energy from carbohydrate (47·2 (SD 3·9) *v.* 45·4 (SD 3·9); $P<0{\cdot}002$) on the large portion condition relative to the standard portion condition. There was no difference in percentage energy from protein between the portion conditions in men (14·4 (SD 1·7); $P=0{\cdot}672$). There were no observed differences in percentage energy from protein, fat or carbohydrate between the portion treatments in women (14·3 (SD 1·7), 40·0 (SD 4·3), 44·6 (SD 4·2), respectively). Larger food portion consumption led to a significant cumulative increase in EI relative to the standard portion treatment in both men (68·2 (SD 17·5) *v.* 58·6 (SD 15·8); $P=0{\cdot}001$) and women (50·3 (SD 9·9) *v.* 40·0 (SD 9·6) MJ; $P=0{\cdot}005$) respectively (Fig. 3). EI from snacks occurred throughout the study day. Although there was variation in the overall percentage increase in portion size from the standard to the large portion condition (0–132 %), the average percentage increase in the portion size of foods selected was 47 (SD 4) % in both men and women.

Total ED (kJ/g), based on all foods and beverages consumed, did not differ between the portion treatments in either men (3·7 (SD 0·7) kJ/g; $P=0{\cdot}508$) or women (3·3 (SD 0·7) kJ/g; $P=0{\cdot}699$). There was no difference in the ED of meals (men 3·5 (SD 0·8) kJ/g, $P=0{\cdot}216$; women 3·1 (SD 0·8) kJ/g, $P=0{\cdot}650$) or snacks (men 7·2 (SD 4·1) kJ/g, $P=0{\cdot}931$; women 9·1 (SD 4·5) kJ/g, $P=0{\cdot}759$) between the portion treatments.

Under the standard portion condition, women and men consumed a mean of 87 (SD 25) and 92 (SD 21) % respectively of the food served to them, compared with 75 (SD 30) and 82 (SD 28) % under the large portion condition. Thus, even though both women and men consumed significantly more food and energy on the large portion condition, both sexes consumed a significantly smaller proportion of the total amount of food served in the large portion condition compared with the standard portion condition. Regression analysis showed that the main predictors of percentage increase in EI were sex (men $P=0{\cdot}013$), a higher external eating score ($P=0{\cdot}007$) and treatment order (large portion $P<0{\cdot}001$). When stratified by sex, treatment order was a significant predictor in both sexes (men $P=0{\cdot}052$; women $P=0{\cdot}007$). A higher external eating score was significantly associated with percentage increase in EI in women ($P=0{\cdot}004$) but not men ($P=0{\cdot}587$). A higher BMI (overweight category) was also a strong predictor of percentage increase in EI in women ($P=0{\cdot}032$) but not men ($P=0{\cdot}304$). Age was significant for women ($P=0{\cdot}039$) but not men ($P=0{\cdot}882$). Total ED, ED of meals or ED of snacks were not associated with percentage increase in EI in men or women, nor were they associated with body-weight change in the large portion condition in men or women.

Appetite and satiety ratings

Self-perceived appetite sensations were differentially influenced by the availability of different-sized food portions.

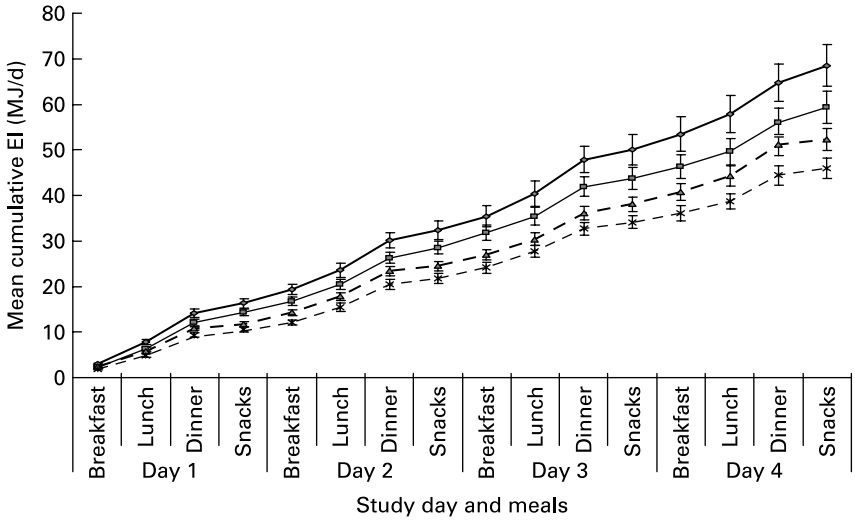

Fig. 3. Cumulative energy intakes (EI) for men (large portion (LP) ▲; standard portion (SP) ■) and women (LP ●; SP – × –) by meal under both study conditions. Data were analysed using paired samples *t* tests. Values are means, with their standard errors represented by vertical bars. There was a significant cumulative increase in EI in men ($P=0{\cdot}001$) and women ($P=0{\cdot}005$).

When ratings on the large portion study period were compared with the standard portion study period, subjects reported that before eating, they were less hungry ($P=0{\cdot}081$), more full ($P=0{\cdot}097$), had less of a desire to eat ($P<0{\cdot}005$) and thought they could eat a smaller amount ($P<0{\cdot}013$). After eating, subjects reported that they were less hungry ($P<0{\cdot}025$), had less of a desire to eat ($P<0{\cdot}004$) and thought that they could eat a smaller amount ($P<0{\cdot}014$) on the large portion condition. Interestingly, after eating, there were no differences in ratings of fullness between the standard and large portion treatments ($P=0{\cdot}581$). Throughout the 4 d in both portion conditions, daily ratings of hunger, fullness, desire to eat or prospective consumption did not significantly vary in either men or women.

End of study perceptions

The end-of-study questionnaire revealed that 55 % of men felt that the portions were 'just about right' on both the standard and large portion conditions for all meals. In the women 62 % reported the portions were 'just about right' on the standard portion condition but 74 % reported that they would have been 'satisfied with smaller' on the large portion condition. Despite this, the women still consumed more food and increased their EI by 10 % under the large portion condition.

Body-weight changes

There was a significant increase in body weight over the 4 d in both men and women in the large portion condition (men, $P=0{\cdot}002$; women, $P=0{\cdot}001$ respectively), but no change in body weight occurred during the standard portion condition (Table 2). The men increased their body weight by 0·9 (SD 1·1) kg (minimum and maximum weight change $-1{\cdot}4$ to $+2{\cdot}4$ kg) and the women by 0·6 (SD 0·6) kg (minimum and maximum weight change $-1{\cdot}1$ to $+1{\cdot}6$ kg); there was no significant difference in weight change between the sexes. The most notable changes in body weight were observed in the overweight men (0·9 (SD 1·1) kg; $P=0{\cdot}014$) and the normal-weight women (0·5 (SD 1·1) kg; $P=0{\cdot}001$) who gained the most body weight during this period.

Discussion

The present study clearly demonstrates that the availability and consumption of large food portions led to significant and sustained increases in EI over a 4 d period. Men and women had EI that were substantially higher (17 and 10 % respectively) under the large portion study condition, relative to the standard portion condition and significantly increased their body weight over the 4 d large portion condition. On a daily basis this corresponded to an average increase in EI of 2·4 and 1·1 MJ in men and women respectively. In addition, there were no observed changes in EI over the 4 d in either men or women and, consequently, it is reasonable to conclude that subjects did not invoke any compensatory mechanisms to down-regulate their EI in the face of large portion sizes. These data are consistent with previous findings in studies under semi-controlled conditions in adults where it has been shown that the availability of large portion sizes led to increased reported EI that were sustained over 2 d[10] and 11 d[9].

Although it may be speculated that a decline in EI would occur at some point in the face of continuous access to larger food portions, this was not observed during the 4 d of the present study. Interestingly, under the large portion size condition, there did appear to be some down-regulation of EI from snacks but this was not sufficient to offset the relatively high EI from meals; thus EI remained 14 % higher relative to the standard portion condition. Consequently, this suggests that, within the standard portion condition, subjects were compensating for the smaller predefined food portions eaten at meals by consuming more snack items. This finding may indicate that consumers have become so accustomed to

British Journal of Nutrition

Table 2. Body-weight (kg) changes in men and women during each study period
(Mean values and standard deviations)

		Standard portion					Large portion				
		Weight 1*		Weight 2*			Weight 1		Weight 2		
	n	Mean	SD	Mean	SD	*P*†	Mean	SD	Mean	SD	*P*†
Men											
All	21	80·1	12·1	80·2	12·1	0·897	79·6	12·4	80·5	12·6	0·002
Normal weight	9	70·8	9·7	70·6	9·4	0·680	69·7	9·7	70·5	10·0	0·065
Overweight	12	87·1	8·5	87·3	8·4	0·503	87·1	8·4	88·0	8·6	0·014
Women											
All	22	65·2	10·3	65·4	10·3	0·362	64·7	10·0	65·3	10·1	0·001
Normal weight	15	59·7	4·7	60·0	4·8	0·295	59·3	4·5	59·8	4·5	0·001
Overweight	7	77·0	9·2	77·1	9·1	0·892	76·4	8·7	76·8	8·8	0·185

* 'Weight 1' was measured on the first morning of each study period. 'Weight 2' was measured on the final morning of each study period.
† Data were compared using paired *t* tests.

larger food portions that are now the 'norm' in many of our eating environments such that standard food portions are no longer perceived as being adequate. From these data, it was calculated that if the large portion condition had been sustained and no compensation in EI was made by the subjects, 5 % weight gain may have resulted after only 4·5 weeks in the men and 5·5 weeks in women.

Other evidence from the study also supports the contention that subjects display variable responses to both physiological and environmental appetite cues. First, from the visual analogue scales, subjects reported less hunger, more fullness, less desire to eat and lower prospective consumption before eating, but surprisingly did not report feeling any fuller as a result of consuming larger food portions. However, they did report significantly less hunger, desire to eat and prospective consumption after eating relative to the standard portion. These apparent contradictions are difficult to reconcile, but imply that environmental cues (large portion sizes) can readily overwhelm a key driver (fullness) of eating initiation and cessation, while other appetite responses (hunger, desire to eat and prospective consumption) are in the direction expected. Second, the DEBQ results demonstrated that the subjects scored highest in the external eating category, indicating that the eating behaviour of the subjects, particularly the women, may be more influenced by environmental food cues, such as the sight, smell and mere presence of food. Finally, findings from the end-of-study questionnaire demonstrate that the majority of men considered the portions to be 'just about right' on both portion conditions. Women, on the other hand, reported that the portions were 'just about right' on the standard portion; even though more food and energy was consumed on the large portion condition, the women noted that they would have been 'satisfied with smaller' food portions.

The major strength of the present study is that it was carried out under fully residential conditions and used the *ad libitum* approach; therefore, it was possible to accurately and covertly monitor all foods, beverages and snacks consumed over a 4 d period, thereby excluding any possible misreporting of food intake. In addition, energy expenditure patterns could be carefully controlled, as subjects were sedentary during the time course of the observations. As this was not a free-living study, it is unclear to what extent the subjects would have compensated for larger portion servings of food had they been studied in a more naturalistic setting. Nevertheless, these data demonstrate that increased portion size can have a transient effect on body weight even over short periods of time and may possibly undermine body-weight regulation in the longer term. This finding is supported by previous research where it has been demonstrated that there is high inter-individual susceptibility to weight gain in environments where food is plentiful[17,18].

Food portion size is one of many dietary and lifestyle risk factors for obesity, but the body of evidence to date has been under semi-controlled conditions from one laboratory in the USA[7–12,19] where subjects were not required to consume all their meals within the test facility; EI may have been limited as more food was not available on request; foods and meals were given out to be consumed at home and food intakes were reported by the subjects. In addition, subjects were not required to be fully residential at the test facility. This is the first study to be carried out under fully residential conditions and provides further evidence of the influence that increasing food portion size may have on inciting over-eating. The trends in eating behaviour shown in the present study may be representative of many industrialised populations, in that individuals may be relying on visual cues and habits as the key stimuli of the amount of food to consume[20]. Therefore, due consideration should be given to developing health promotion programmes that focus on consumer education in the area of portion control. A possible approach could be to attempt to alert individuals to the importance of recognising and responding to the physiological cues of appetite and satiety, as well as an increased awareness of the environmental factors, such as food portion size, that can influence increased food consumption. However, the onus for the 'downsizing' of large portion sizes to help bring food portions back in line with energy requirements cannot rest with consumers alone, and will need to be facilitated by appropriate measures on the part of the food industry.

In conclusion, the present study demonstrated that the availability and consumption of large food portions had a significant and sustained effect on EI over four consecutive days under fully controlled residential conditions. Increased food

and energy consumption did affect appetite sensations but subjects did not adjust their intakes accordingly. The data from the present study provide evidence to support the general consensus that increased portion size may be a major contributing factor in inciting excess EI and adiposity.

Acknowledgements

The present study was commissioned by the Food Standards Agency (project N09021). There are no conflicts of interest. The contributions of the authors were as follows: M. B. E. L. was the principal investigator and is the guarantor. M. T. K. executed the study, conducted data analysis and wrote the paper. M. B. E. L., J. M. W. W. and P. J. R. planned and designed the study, M. B. E. L., J. M. W. W., P. J. R., R. W. W. and M. P. H. F. contributed to data analysis and interpretation and final drafting of the paper. K. L. R. advised on statistical analysis and final drafting of the paper. S. B. and A. F. contributed to study execution, data collection and analysis.

References

1. Ebbeling CB, Pawlak DB & Ludwig DS (2002) Childhood obesity: public-health crisis, common sense cure. *Lancet* **360**, 473–482.
2. Ledikwe JH, Ello-Martin JA & Rolls BJ (2005) Portion sizes and the obesity epidemic. *J Nutr* **135**, 905–909.
3. Young LR & Nestle M (2002) The contribution of expanding portion sizes to the US obesity epidemic. *Am J Public Health* **92**, 246–249.
4. Nielsen SJ & Popkin BM (2003) Patterns and trends in food portion sizes, 1977–1998. *J Am Diet Assoc* **289**, 450–453.
5. Rolls BJ (2003) The supersizing of America: portion size and the obesity epidemic. *Nutr Today* **38**, 42–53.
6. Levitsky DA & Youn T (2004) The more food young adults are served, the more they overeat. *J Nutr* **134**, 2546–2549.
7. Rolls BJ, Morris EL & Roe LS (2002) Portion size of food affects energy intake in normal-weight and overweight men and women. *Am J Clin Nutr* **76**, 1207–1213.
8. Rolls BJ, Roe LS, Kral TV, *et al.* (2004) Increasing the portion size of a packaged snack increases energy intake in men and women. *Appetite* **42**, 63–69.
9. Rolls BJ, Roe LS & Meengs JS (2007) The effect of large portion sizes on energy intake is sustained for 11 days. *Obesity (Silver Spring)* **15**, 1535–1543.
10. Rolls BJ, Roe LS & Meengs JS (2006) Larger portion sizes lead to a sustained increase in energy intake over 2 days. *J Am Diet Assoc* **106**, 543–549.
11. Rolls BJ, Roe LS & Meengs JS (2004) Salad and satiety: energy density and portion size of a first-course salad affect energy intake at lunch. *J Am Diet Assoc* **104**, 1570–1576.
12. Rolls BJ, Roe LS, Meengs JS, *et al.* (2004) Increasing the portion size of a sandwich increases energy intake. *J Am Diet Assoc* **104**, 367–372.
13. Wansink B & Kim J (2005) Bad popcorn in big buckets: portion size can influence intake as much as taste. *J Nutr Educ Behav* **37**, 242–245.
14. Department of Health (1991) *Dietary Reference Values for Food Energy and Nutrients for the United Kingdom*. London: The Stationery Office.
15. van Strien T, Frijters J, Bergers G, *et al.* (1986) The Dutch Eating Behaviour Questionnaire (DEBQ) for assessment of restrained, emotional, and external eating behaviour. *Int J Eat Disord* **5**, 295–315.
16. Hill AJ & Blundell JE (1982) Nutrients and behaviour: research strategies for the investigation of taste characteristics, food preferences, hunger sensations and eating patterns in man. *J Psychiatr Res* **17**, 203–212.
17. Jebb SA, Siervo M, Fruhbeck G, *et al.* (2006) Variability of appetite control mechanisms in response to 9 weeks of progressive overfeeding in humans. *Int J Obes* **30**, 1160–1162.
18. Siervo M, Frühbeck G, Dixon A, *et al.* (2007) Efficiency of autoregulatory homeostatic responses to imposed caloric excess in lean men. *Am J Physiol Endocrinol Metab* **294**, E416–E424.
19. Rolls BJ, Roe LS & Meengs JS (2006) Reductions in portion size and energy density of foods are additive and lead to sustained decreases in energy intake. *Am J Clin Nutr* **83**, 11–17.
20. Blundell JE & King NA (1996) Overconsumption as a cause of weight gain: behavioural-physiological interactions in the control of food intake (appetite). *Ciba Found Symp* **201**, 138–154.

British Journal of Nutrition

Appendix 1. Food and snack choices available to subjects

	Standard portion				Large portion				
Food item	Food weight (g)	Protein (g)	Fat (g)	CHO (g)	Food weight (g)	Protein (g)	Fat (g)	CHO (g)	ED (kJ/g)
Breakfast									
Branflakes	45	4·6	1·1	32·0	65	6·6	1·6	46·3	14·1
Cornflakes	30	2·4	0·3	26·9	50	4·0	0·5	44·8	16·0
Muesli	50	4·9	3·0	36·1	70	6·9	4·1	50·5	15·4
Rice Krispies	30	1·8	0·3	27·9	50	3·1	0·5	46·5	16·3
Sugar	25	0·0	0·0	5·3	50	0·0	0·0	10·5	16·8
White bread	39	6·6	1·5	38·5	78	7·1	1·6	41·4	10·0
Wholemeal bread	43	6·8	1·8	30·2	86	8·3	2·2	37·0	9·2
Flora	10	0·0	8·3	0·0	20	0·0	16·6	0·0	30·7
Butter	7	0·0	5·7	0·0	14	0·1	11·4	0·0	30·3
Jam or marmalade	40	0·0	0·0	13·9	50	0·1	0·0	34·8	11·1
Milk	560	19·3	9·6	26·7	1064	36·1	18·0	50·0	2·0
Orange juice	200	1·0	0·2	17·6	300	1·5	0·3	26·4	1·5
Grapefruit juice	200	0·8	0·2	16·6	300	1·2	0·3	24·9	1·4
Lunch									
Red pepper soup	179	1·4	5·2	5·6	358	2·9	10·4	11·1	1·7
Potato and leek soup	180	1·8	3·4	6·3	360	3·6	6·8	12·6	1·4
Chicken	75	18·6	4·1	0·0	100	24·8	5·4	0·0	6·2
Cheese	40	10·2	14·0	0·0	50	12·7	17·5	0·1	17·3
Lettuce	25	0·2	0·1	0·5	30	0·2	0·1	0·6	0·5
Onion	10	0·2	0·1	0·3	20	0·4	0·1	0·6	1·0
Tomato	30	0·2	0·1	0·9	45	0·3	0·1	1·4	1·0
Tuna	50	11·8	0·3	0·0	75	17·6	0·5	0·0	4·2
Ham	38	7·0	1·3	0·4	63	11·6	2·1	0·6	4·5
Mayonnaise	15	0·2	11·3	0·3	30	0·3	22·7	0·5	28·4
Sweet chilli sauce	15	0·1	0·0	8·2	30	0·1	0·0	16·3	9·4
Dinner									
Pasta carbonara	261	19·1	47·2	48·3	350	25·6	63·4	64·8	10·9
Carbonnade of beef	375	48·0	25·5	19·9	500	64·0	34·0	26·5	5·5
Chicken chasseur	262	33·5	5·0	6·8	349	44·7	6·6	9·1	3·3
Chicken curry	443	67·3	25·7	20·4	543	82·5	31·5	25·0	5·5
Sauté potatoes	100	3·1	4·7	27·3	150	4·7	7·1	41·0	6·6
Side salad	150	1·1	0·6	5·7	230	1·6	0·9	8·7	0·9
Mashed potatoes	175	3·3	4·7	26·6	220	4·2	5·9	33·4	3·8
Steamed vegetables	90	3·6	0·8	6·3	120	4·8	1·1	8·4	2·1
Boiled rice	180	4·1	13·7	53·3	290	6·7	22·0	85·8	7·9
Naan bread	60	4·7	4·4	30·1	139	10·8	10·2	69·8	12·1
Tart tatin	125	1·8	21·8	38·5	167	2·3	29·1	51·4	11·6
Crème brûlée	200	4·8	52·0	23·6	300	7·2	78·0	35·4	11·9
Strawberry cheesecake	180	7·0	26·1	35·5	300	11·7	43·5	59·1	9·2
Warm chocolate fondant	71	4·0	21·0	30·3	107	6·0	31·6	45·7	18·7
Fresh cream	20	0·4	8·1	0·5	30	0·6	12·1	0·8	15·7
Snacks									
Coke	330	0·0	0·0	34·7	500	0·0	0·0	52·5	1·7
Sprite	330	0·0	0·0	18·5	500	0·0	0·0	28·0	0·9
Fanta	330	0·0	0·0	34·0	500	0·0	0·0	51·5	1·7
Pringles	30	1·4	9·0	16·8	50	2·4	15·0	28·0	21·4
Fruit & Nut Bar	36	2·8	9·5	19·8	49	3·9	12·9	27·0	20·5
Maltesers	22	1·7	5·0	13·6	37	2·9	8·5	22·8	20·3
Dairy Milk	40	3·1	12·3	22·8	49	3·8	15·0	27·9	21·8
Kit Kat	21	1·6	5·5	13·2	42	3·2	10·9	26·5	21·0
Potato crisps	25	1·4	8·6	13·3	35	2·0	12·0	18·7	22·2
Mars	36	1·6	6·6	27·8	63	2·8	11·5	48·7	19·9
Snickers	42	4·0	11·7	23·4	63	5·9	17·5	35·2	20·8
Nutrigrain	37	1·5	3·3	24·1	37	1·5	3·3	24·1	15·1
Cereal bar	23	1·8	1·8	17·0	23	1·8	1·8	17·0	16·9
Yoghurt	200	8·4	2·2	27·4	200	8·4	2·2	27·4	3·3
Apple	125	0·5	0·2	22·8	175	0·5	0·2	22·8	3·0
Banana	145	1·7	0·4	33·6	200	2·4	0·6	46·4	4·0
Grapes	100	0·4	0·1	15·4	150	0·6	0·2	23·1	2·6
Coffee	190	0·4	0·0	0·6	260	0·5	0·0	0·7	0·1
Tea	190	0·2	0·0	0·0	260	0·2	0·0	0·0	0·0
Herbal tea	190	0·0	0·0	0·4	260	0·0	0·0	0·5	0·1
Water	500	0·0	0·0	0·0	500	0·0	0·0	0·0	0·0

CHO, carbohydrate; ED, energy density.

British Journal of Nutrition