



Review

Large portion sizes increase bite size and eating rate in overweight women



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HIGHLIGHTS

- Increasing the portion size of a meal is associated with marked changes in eating behavior.
- Average bite size increased by 0.22 g for every 100 g increase in portion size.
- Larger portions led to an increase in eating rate up to about 540 g.
- Meal duration increased by 22.5% for every 100 g increase in portion size.
- Reducing bite size and slowing eating rate may reduce the risk of overconsumption.

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ABSTRACT

Objective: Larger food portions lead to increased intake but the mechanism behind this effect is unclear. We investigated the effect of portion size on bite size, eating rate, deceleration rate, and meal duration.

Design and methods: Thirty-seven overweight women attended 5 visits after a 3 h fast and consumed a 229, 303, 400, 529 or 700 g portion of a lunch meal in random order. Meal eating parameters were measured with the Sussex Ingestion Pattern Monitor. Data were analyzed with mixed effects models.

Results: Average bite size increased by 0.22 g for every 100 g increase in portion size ($p = 0.001$); portion size had a non-linear effect on eating rate, increasing with portion sizes up to about 540 g ($p = 0.01$). Deceleration rate (reduction in speed of eating) decreased by 20% ($p < 0.001$) and meal duration increased by 22.5% for every 100 g increase in portion size ($p < 0.001$), relative to the smallest portion.

Conclusions: Increasing portion size led to a larger bite size and faster eating rate, but a slower reduction in eating speed during the meal. These changes may underlie greater energy intakes with exposure to large portions. Interventions to reduce bite size and slow eating rate may provide individuals with strategies to reduce the risk of overconsumption.

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1. Introduction

Exposure to larger portion sizes has been linked with increased intake both in children and adults, and across a variety of foods and settings [1,2] although, the mechanisms underpinning this effect are unclear. Secular increases in portion sizes of many foods mean that individuals may need to develop personal coping strategies to avoid overeating. Understanding the factors associated with overeating in the face of larger portions may help to develop weight management interventions.

The microstructure of meal eating (the behavioral components associated with eating, including bite size, eating rate, meal duration, and the reduction in eating rate, also known as deceleration rate) is of increasing interest in the attempt to identify targets for interventions to constrain energy intake. Previous work has suggested that larger portions lead to an increase in bite size [3–5], as people increase the amount on their utensil in response to larger amounts on the plate [5]. A recent systematic review of controlled laboratory studies has shown that a faster eating rate is associated with greater energy intake [6]. Some of these parameters are inherently linked, for example, eating rate is affected by bite size [7,8], which is associated with the amount of food eaten [3,9].

Current evidence on how portion size affects eating behavior microstructure is limited to observing the number of bites in order to estimate bite size [5] but modern technology now allows the precise measurement of bite size and other related parameters [10]. The current study tested the hypothesis that increasing the portion size of a meal would lead to an increase in bite size. Secondary objectives were to explore changes in overall eating rate, deceleration rate and meal duration. We focused on overweight women only to make our sample more homogeneous especially as the portion size effect may differ across genders [11,12].

2. Methods and procedures

2.1. Participants and recruitment

Healthy women aged 18–60 years with a BMI between 25 and 35 kg/m² were recruited from Cambridge and surroundings. As eating behavior microstructure parameters may differ between males and females [13] only women were recruited to reduce heterogeneity. It was estimated that 35 women were required to achieve 90% power (at a significance level of 0.05) to detect a 2.4 g difference in average bite size when portion size is doubled [5], assuming a standard deviation within-subjects (women) of 3 g/bite [13]. To account for possible drop outs, 40 women were recruited.

To avoid alterations in normal eating behavior due to knowledge of the true study aims, the study was advertised as “investigating the influence of the eating environment on meal satisfaction”. Exclusion criteria included: smoking; currently dieting; consuming breakfast less than 5 days per week; being pregnant, planning a pregnancy or breastfeeding; disliking or restricting of the test foods (e.g. vegetarianism, food allergies); presence of an eating disorder, defined as a score ≥ 11 on the Eating Attitudes Test (EAT-26) [14,15]; having a medical condition (e.g. gastro-intestinal disorders) or taking medication

(e.g. antidepressants) that can affect appetite; self-reported depression, mental illness or psychiatric disorder; excessive alcohol intake (> 14 units/week); and performing ≥ 10 h/week intense physical activity. Weight and height were recorded at a screening visit with a SECA scale and stadiometer to the nearest 0.1 kg and 0.1 cm respectively, from which BMI was calculated. Candidates completed the EAT-26 questionnaire. Those meeting eligibility criteria for BMI and EAT-26 scores were asked to attend a training session.

2.2. Measurement of eating behavior parameters

The Sussex Ingestion Pattern Monitor (SIPM) was used to measure bite size, eating rate, deceleration rate and meal duration [10]. The SIPM consists of a concealed scale (Sartorius Cubis model), connected with a serial line to a PC, and secured beneath a purpose-built table under a hole, on top of which a place mat was secured to allow positioning of the plate. For this study, the software in the PC was programmed to record weight readings from the scale at 2 second intervals (precision 0.1 g), from which average bite size (the difference between each two consecutive weight records), eating rate (grams consumed per minute) and deceleration rate (grams consumed per squared minute) were calculated. The meal duration was divided into quartiles to explore changes in eating parameters over time [16]. Due to the high sensitivity of the SIPM equipment the data for bite size required cleaning. Records of < 1 g or > 23.4 g were excluded on the basis that they represented scale background noise or the result of the participant unknowingly applying weight or movement while sitting at the SIPM. These cut-off values were chosen after verifying the minimum and maximum weights of the test food that could realistically be loaded on the study fork.

2.3. Training session

The training session was designed to familiarize the participant with the individual eating booth and equipment where the SIPM was installed to minimize erroneous readings. Participants were asked to taste and rate the pleasantness of 4 foods, one of which was the test food (orange juice, tomato and cheese pasta bake, chili-con-carne, chocolate mousse), using electronic, 100 mm visual analogue scales (VAS). Immediately after the taste test participants were served 125 g of a chocolate mousse and asked to consume it in full while following explicit instructions to avoid leaning on the table while eating, position the spoon outside the bowl after finishing, and avoid tampering with the table and settings (i.e. placemat and screen). In line with the cover story, the volunteers were told that the eating and sitting requirements were necessary to standardize eating environment conditions across the participants. After the training session one participant disliking (i.e. a liking score < 40 mm) the chili-con-carne meal was excluded and replaced.

2.4. Experimental procedures

The participants attended 5 study visits at a selected lunchtime between 11:30 am and 2:30 pm, standardized for each individual and following a 3 h fast. The average starting time was 12:00 noon. The experimental conditions consisted of 5 different portion sizes of a main

meal presented in random order (see “Test foods” below). Each visit was scheduled between 2 and 20 days apart. The participants were asked to consume their usual breakfast at home at the same time on each study day, to avoid alcohol and to keep evening meals and activity levels similar the morning of and the day before each visit. On arrival to the volunteer suite, the participants were given 200 ml of water to consume in full to standardize thirst levels and completed pre-meal appetite ratings using electronic VAS questionnaires at the eating monitor station. The participants were then presented with one of the portions of the test meal and asked to consume it in full while following the same instructions specified at the training session. Time for eating the lunch was unrestricted. Immediately after eating, the participants completed another set of electronic VAS appetite questionnaires. To avoid any confounding effects on meal parameters, drinks were not allowed during the meal but ad libitum water was offered at the end of the session. At the end of the last visit, the participants completed the Three Factor Eating Questionnaire [17] and were debriefed about the true purpose of the study. After the debriefing the investigator asked the participants if they were aware of the true purpose of the study and recorded any spontaneous comments (such as noticing changes in portion sizes across sessions and being aware of the covert equipment). Ethical approval for the study was obtained from the University of Cambridge, Psychology Research Ethics Committee. The participants gave written informed consent and were compensated for participation.

2.5. Appetite ratings

Pre- and post-meal hunger and fullness levels were assessed using validated, electronic visual analogue scales (VAS) programmed as part of the SIPM [18]. The post-meal questionnaire included three distractor questions on liking, satisfaction and the extent to which eating environment had affected meal satisfaction, which were not analyzed.

2.6. Test foods

The lunch meal consisted of chili-con-carne sauce with rice, provided in portion sizes of 229 g, 303 g, 400 g, 529 g or 700 g (representing 1.3, 1.7, 2.2, 2.9 and 3.8 MJ/portion respectively). The proportion of sauce to rice used was 220 g of sauce for each 180 g of cooked rice [19]. All food portions were weighed both prior and after meals using Salter™ scales (precision 1 g). The energy density of the final meal was of 1.32 kcal/g (5.5 kJ/g). The five selected portion sizes represented 5 equally spaced portions in logarithmic units, based on human perception laws [20]. The largest and smallest portions represented a 75% increase, and a 43% decrease, respectively from the average portion of a chili-con-carne main course (400 g) [19]. Pilot testing in a sample of 7 non-participating women showed that they were able to consume portions of the test meal in the range of 566–800 g. All meals were presented in exactly the same format, and accompanied by the same crockery and cutlery.

2.7. Statistical analyses

Outcome variables (bite size, eating rate, deceleration rate, and meal duration) were checked for normality using histograms and quantile–quantile plots. Deceleration rate and meal duration were not normally distributed so all analyses were performed on natural logarithm transformed data.

Linear mixed effect models were fitted to the four outcome variables separately. We fitted each outcome variable with a linear mixed effect model including a linear term (or a categorical variable, see Supplementary information) for portion size, participant characteristics (age, BMI, chili-con-carne liking score, TFEQ restraint, disinhibition and susceptibility to hunger scores), visit number, and pre-meal hunger and fullness as covariates. The effects of covariates in the models were considered to be statistically significant at the 5% level. All models included a random

intercept to account for the repeated observations for each individual. All models were fitted using maximum likelihood estimation and likelihood ratio tests were used for model selection. Plots of residuals were used to check the goodness of fit of the selected models for each outcome.

The final models for bite size and eating rate included portion size, visit number and pre-meal fullness as covariates, whereas those for meal duration and deceleration rate included portion size and pre-meal fullness.

Statistical analyses were performed using the R-language free software, version 3.0.2 (R Project for Statistical Computing, www.r-project.org).

3. Results

3.1. Participants

A total of 40 female participants were enrolled in the study. Three participants did not complete the study due to conflicting commitments and were excluded from the analysis. Three subjects left more than 100 g (~15%) of the meal in the largest portion condition, and a fourth subject left more than 30% (351 g). Based on the main outcome variables (bite size, eating rate, deceleration rate and meal duration) none of these subjects were considered outliers therefore data for these participants were included in the analyses. Characteristics of the 37 participants included in the analysis are shown in Table 1.

3.2. Effect of portion size on eating behavior microstructure parameters

To provide a description of the data Table 2 shows the sample mean (\pm SD) for each outcome variable, lunch intake, and pre- and post-meal appetite ratings across portion size conditions. Due to equipment faults (i.e. scale not measuring food weight continuously), and/or participants unconsciously unsettling the equipment, 33% of the data for bite size, 7% for eating rate, deceleration rate and meal duration, and 1% for pre-meal hunger and post-meal hunger could not be recovered. Missing values were missing completely at random with respect to the portion size condition, thus only available data were used for further analysis.

The estimated regression coefficient of portion size on bite size was 0.0022 (95% CI: 0.00077, 0.0037; $p = 0.001$). This suggests that for every 100 g increase in portion size there is an estimated 0.22 g increase in bite size (Fig. 1a).

The regression coefficient of portion size on eating rate was 0.027 (95% CI: 0.013, 0.041; $p < 0.001$). The regression coefficient of the quadratic term for portion size was -0.00012 (95% CI: -0.00022 , -0.00003 ; $p = 0.01$). The quadratic term suggests that eating rate increases in response to portion sizes up to 540 g, but reduces in response to portion sizes larger than this (Fig. 1b).

The regression coefficient of portion size on meal duration was 0.0020 (95% CI: 0.0018, 0.0022; $p < 0.001$). Therefore for every 100 g increase in portion size, the meal duration increases by an estimated 22.5% (Fig. 1c).

Table 1
Participant characteristics.

Characteristic (n = 37)	Mean \pm SD
Age (years)	43.7 \pm 10.7
Weight (kg)	81.1 \pm 9.8
BMI (kg/m ²)	29.2 \pm 2.6
Restraint ^a (scores 0 to 21)	8.5 \pm 3.8
Disinhibition ^a (scores 0 to 16)	8.8 \pm 3.5
Hunger ^a (scores 0 to 14)	6.6 \pm 3.3

BMI: body mass index.

^a Score from the Three Factor Eating Questionnaire [17].

Table 2
Mean \pm SD bite size, eating rate, deceleration rate, meal duration, lunch intake, and pre- and post-meal appetite ratings (taken immediately before and after the meal) across portion size conditions.

Portion size	229 g	303 g	400 g	529 g	700 g
Average bite size (g)	8.1 \pm 1.8	8.2 \pm 2.2	8.9 \pm 2.2	9.4 \pm 2.2	9.1 \pm 2.2
Average eating rate (g/min)	56 \pm 17	63 \pm 21	66 \pm 23	67 \pm 18	64 \pm 22
Average deceleration rate (g/min ²) ^a	12.6 \pm 2.0	11.9 \pm 2.1	10.1 \pm 1.9	7.9 \pm 1.8	5.4 \pm 2.1
Meal duration (min) ^a	4.1 \pm 1.4	5.0 \pm 1.4	6.3 \pm 1.4	8.2 \pm 1.3	11.1 \pm 1.4
Lunch intake (g)	228.0 \pm 1.4	298.5 \pm 11.7	392.8 \pm 27.7	521.5 \pm 13.2	673.4 \pm 67.5
Pre-meal hunger	79.0 \pm 14.0	76.5 \pm 18.5	75.0 \pm 19.9	75.7 \pm 18.1	79.7 \pm 16.4
Pre-meal fullness	20.4 \pm 20.4	22.7 \pm 20.8	18.8 \pm 18.0	21.2 \pm 18.2	19.2 \pm 17.9
Post-meal hunger	24.7 \pm 21.3	19.8 \pm 23.7	14.1 \pm 21.1	4.6 \pm 9.2	1.1 \pm 2.2
Post-meal fullness	67.9 \pm 18.9	79.7 \pm 16.4	85.8 \pm 12.6	90.4 \pm 13.0	97.7 \pm 4.6

^a This variable was log_e transformed for analysis. Geometric mean and SD are presented.

The regression coefficient of portion size on deceleration rate was -0.0018 (95% CI: -0.0022 , -0.0014 ; $p < 0.001$). Therefore for every 100 g increase in portion size, the deceleration rate reduces by an estimated 20% (Fig. 1d).

Visual inspection of the temporal curves for the main outcome variables over the course of the meal revealed no differences in the temporal bite size and eating rate across conditions. However there appeared to be a greater reduction in deceleration rate over the course of the meal in the smaller portion sizes compared with the larger ones (data not shown).

Estimates comparing the mean outcome variable for each portion size condition with that of the smallest portion size can be found in the Supplementary information.

3.3. Debriefing

Thirty-two out of the 37 participants reported noticing a change in the portion size of the test meal over the course of the study. Only four participants reported being aware of or suspecting the existence of covert equipment as part of the eating station. Two reported that they thought the purpose of the study included measuring the speed of eating.

4. Discussion

Large portions, in particular of high energy dense foods, challenge innate human appetite control systems and may lead to weight gain

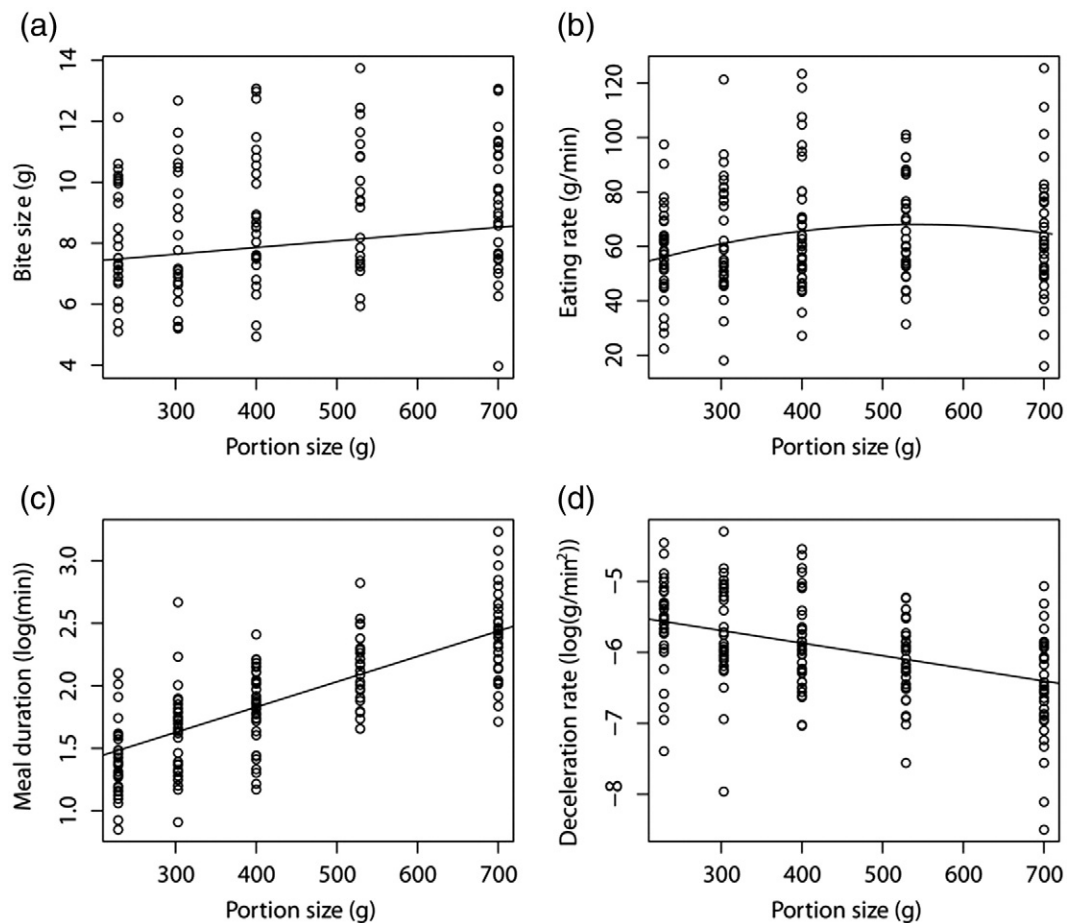


Fig. 1. Scatterplots with fitted regression curves for (a) bite size, (b) eating rate, (c) meal duration (natural logarithm transformed), and (d) deceleration rate (natural logarithm transformed) against portion size provided. All regression curves were adjusted for the effect of repeated measures of the same individual and participant characteristics.

[21,22]. This study showed that increasing the portion size of a main meal from around half of a standard portion to 75% larger led to marked changes in eating behavior which provide new insights into appetite control. As portion size increased, there was a linear increase in bite size. Average bite size increased by 0.22 g for every 100 g increase in portion size, this represents a 2–3% increase above the average bite size observed in our study (8–9 g); and a 3–4% increase of a typical bite size reported in the literature (5–8 g) [23]. This confirms and extends previous findings [5] by using a tightly controlled environment and highly sensitive modern equipment that allows the precise measurement of individual bites together with other components of eating behavior [10]. In ad libitum studies larger bite sizes have been shown to increase eating rate, likely mediated by a reduction in meal duration [24]. However in the larger portion size conditions in our study, the meal duration and eating rate also increased, suggesting that the effects of these different parameters of eating behavior may be independent.

Overall, an increase in portion size was associated with an increase in eating rate. Previous research has shown that presenting overweight participants with a liked food, in large amounts, increases the desire to eat [25] which could translate into an urge to eat the food more quickly. This could represent a decrease in the oral processing time per gram, probably independent of chewing speed though, which is very constant in humans [23]. However unlike the linear increase in bite size and meal duration, we observed a threshold, at about 540 g, around 15% greater than a reference portion size, beyond which eating rate began to decrease. Although the specific reason for this is unclear, portion sizes greater than 540 g are particularly large (35% larger than the national reference portion) and, unusually, the participants were required to consume the full portion. This may have encouraged the participants to artificially 'pace' their eating rate throughout the meal, relative to a more naturalistic context. This threshold may also be related to the asymmetry of appetite control whereby hunger cues are stronger than satiety signals [26]. Thus smaller portions may prompt differential effects on the microstructure of eating, relative to portion sizes above conventional norms.

Progressive reductions in the speed of eating (deceleration rate) occurred in each quarter of the meal in all portion conditions, however the speed of eating reduced more quickly in the smaller portion size conditions and over a shorter absolute time-period. In other words, the speed of eating was more consistent (i.e. did not decrease so quickly) with larger portions. A gradual attenuation in eating speed, starting very early in the meal, is a common trait of human eating behavior and is associated with parallel increases in satiation at 1–2 min after the start of the meal [16]. The reason for the slower deceleration in the larger portions is unclear, but may have been attributable to the requirement to finish an unusually large portion. This on the other hand may have been perceived as a single unit, thus prompting plate-cleaning (unit bias effect) [27]. Further research is needed to determine if this also occurs in an ad libitum setting. If this is a reproducible finding, it is plausible that deceleration may be related to a priming effect of the food that is left on the plate, whereby the participants took longer to slow down their eating speed with larger portion sizes because they continued to be exposed to a large quantity of food for longer relative to the smaller portion size conditions [28]. Therefore they maintained their initial eating speed for longer in an attempt to finish the meal more quickly to satisfy a pre-defined hunger goal [29].

This was a controlled experimental study in overweight women only to decrease variability, the results may not be generalizable to other groups and free-living conditions where the participants are eating ad libitum.

The inter-relationships between the various meal eating parameters is complex and affected by many factors, some of which were not measured in this study. This includes the number of bites, chewing speed [8,23], oral processing time [9,23], the food's flavor and textural properties and its ability to elicit sensory-specific satiety [9,30–32]. Some of these factors may influence people's perceptions of how

much they are eating which may in turn affect their coping strategies when exposed to large portion sizes. We did not seek to study the impact of any post-prandial compensatory behavior or later changes in perceived appetite or satiety peptides [16,33]. Although we observed slightly higher hunger ratings immediately after consumption of the smaller portion sizes compared with the larger ones, the magnitude of these changes was small (20 mm in a scale of 100, similar results for fullness). These results are in agreement with some studies in the literature suggesting that altering portion size is not necessarily linked with increases in perceived hunger [34,35] and, as manipulating eating rate does not appear to alter perceived appetite [6], strategies leading to portion control via reductions in eating rate may be sustainable.

5. Conclusion

This study shows that changing portion sizes alters the microstructure of eating. Changes in eating rate and bite size with larger portions may underpin increased energy intakes, while reductions in these parameters with small portions may explain why smaller portions can help constrain intake [36]. While excessive portion sizes persist in the environment, interventions to reduce bite size and slow eating rate may provide individuals with coping strategies to reduce the risk of overconsumption.

Conflicts of interest

The authors report no conflicts of interest.

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EAR, HL and SAJ conceived the study; EAR and MT collected and prepared the data for analysis; JW and IST performed the statistical analyses. All authors were involved in writing the paper and had final approval of the submitted and published versions.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <http://dx.doi.org/10.1016/j.physbeh.2014.11.041>.

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