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Session 1: Balancing intake and output: food *v.* exercise

The control of meal size in human subjects: a role for expected satiety, expected satiation and premeal planning

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Unlike energy expenditure, energy intake occurs during discrete events: snacks and meals. The prevailing view is that meal size is governed by physiological and psychological events that promote satiation towards the end of a meal. This review explores an alternative and perhaps controversial proposition. Specifically that satiation plays a secondary role, and that meal size (kJ) is controlled by decisions about portion size, before a meal begins. Recently, techniques have been developed that enable us to quantify 'expected satiation' and 'expected satiety' (respectively, the fullness and the respite from hunger that foods are expected to confer). When compared on a kJ-for-kJ basis, these expectations differ markedly across foods. Moreover, in self-selected meals, these measures are remarkably good predictors of the energy content of food that ends up on our plate, even more important than palatability. Expected satiation and expected satiety are influenced by the physical characteristics of a food (e.g. perceived volume). However, they are also learned. Indeed, there is now mounting evidence for 'expected-satiation drift', a general tendency for a food to have higher expected satiation as it increases in familiarity. Together, these findings show that important elements of control (discrimination and learning/adaptation) are clearly evident in plans around portion size. Since most meals are eaten in their entirety, understanding the nature of these controls should be given high priority.

Energy intake: Portion size: Expected satiety: Expected satiation: Learning

Frontline doctors and clinicians deal with the consequences of obesity on a daily basis; diabetes and heart disease in particular. What makes this such a fascinating problem is that there is very little consensus around its cause. We often hear about an 'obesogenic environment' that promotes overeating. However, this level of explanation is merely descriptive. What is needed is a better understanding of our interaction with our food environment, how certain foods and meals promote overconsumption and why certain individuals are more likely to eat in excess of need.

Under free-living conditions, meal choice and portion size are often assessed using a food diary, or some form of retrospective questionnaire. Unfortunately, problems with omission and underestimation are well documented(1). By contrast, in animals, food intake can be measured accurately. Generally, a large portion of food is provided and intake is estimated based on the amount that remains after a meal has terminated. This *ad libitum* feeding paradigm has proved extremely helpful because it enables researchers to explore determinants of meal size under tightly controlled conditions.

Ad libitum eating is also assessed in studies of human dietary behaviour. Typically, participants are given a large portion of a single or a multi-item meal and are told to eat until they feel comfortably full. As in animals, the control of meal size is generally attributed to the cessation of a desire to eat (satiation) that is brought about by psychological and physiological events that occur during and towards the end of a meal. In this context, the *ad libitum*

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eating paradigm is regarded as an ideal tool, because it provides an ecologically valid environment in which the control of normal or ‘free living’ behaviour can be expressed and measured.

The present discussion focuses specifically on behavioural and cognitive controls of meal size in human subjects (broader issues relating to the biological controls of appetite and hunger are beyond the scope of this article). Specifically, it explores the proposition that meal size is not governed solely or perhaps even primarily by satiation (within-meal events). Rather, in human subjects, the control of meal size is learned and expressed in the cognitive activity associated with meal planning, before a meal begins.

Researchers who use ‘amount eaten’ as their primary dependent variable have found intake to be influenced by endocrine and neural controls that signal when to terminate a meal(2,3), and by a range of extrinsic factors. These include the variety of available foods(4,5), palatability(6), the number of people present at a meal(7), the amount of food that is presented(8), cognitive distraction(9,10) and cognitive disinhibition(11). Together, these findings have been taken to indicate that environmental or situational factors play a very important role, that satiation may be easily overridden and that meal size is not tightly controlled(12). Instead, meal size is described as elastic and governed largely by ‘non-regulatory’ psychological, sociological and cultural factors(13).

The control of meal size in human subjects: an alternative perspective

Research that highlights exogenous causes of dietary excess is likely to be well received. But should it be taken to imply that human subjects express very little control over meal size? As is often the case, the answers that we get depend largely on where we look. Unlike most animals, the majority of our meals require some form of preparation, either by the consumer or by another agent (e.g. a chef or food company). Often this process is highly complex. Indeed, eating lots of raw food is potentially very unhealthy(14), suggesting that cooking has become a biological necessity. The importance of cooking can be traced back to early *homo erectus* and it coincides with a decrease in masticatory apparatus and gut size, and an increase in brain size(15). Cooking can greatly increase the energy that is extracted from food(16) and it kills potential pathogens. However, it also requires preparation, fire and time. In this context, it makes little sense to cook food, consume food and then rely on the development of satiation to meter and control further food preparation and intake. Instead, it would seem sensible to acquire a capacity to anticipate future need, and to do this at the point at which food is selected and prepared. This strategy optimises effort, minimises food wastage and protects against hunger and the need to prepare unplanned meals(17).

Given the historic relevance and biological importance of meal planning, it is surprising that this activity is often overlooked as an important mechanism in human dietary control. Indeed, until recently, very little was known about the learning and cognition that underpins decisions about portion and meal size.

Introducing expected satiety and expected satiation

Perhaps one reason why we have known so little about meal-size selection is that it has been unclear how to measure expectations relating to the consequences of consuming different foods and portions. In an attempt to address this problem my colleagues and I developed an approach that uses a ‘method of constant stimuli’(18). This classical psychophysical technique is commonly used by researchers of human sensory perception. In our version, one food of fixed and known energy content is displayed on a computer screen. Next to this ‘standard’ picture a different food is displayed. On each trial, the amount of this second ‘comparison’ food changes and the participant is asked to indicate which of the two foods will stave off hunger for the longest period. After fifty six trials, we have sufficient data to estimate the size of the comparison food that would be needed for the standard to be selected 50 % of the time. This ‘point of subjective equality’ is important, because it reveals the energy content of the comparison food that is needed for the comparison food and the standard to be expected to deliver the same satiety. If the standard remains fixed, then we can compare ‘expected satiety’ across several foods.

In our first study, we compared the expected satiety of eighteen commonly consumed foods(18). This revealed surprisingly large differences. Indeed, when quantified in this way, some foods were expected to confer five to six times more satiety than others (kJ for kJ). These comparisons involved foods such as potatoes (high expected satiety) and a chocolate confectionery (peanut M&M’s; low expected satiety), perhaps not very representative of everyday meals. Nevertheless, even when comparing ‘staple’ meals, such as pizza and pasta, we found large differences (a nominal 837 kJ portion of pasta was expected to confer the same satiety as a 1612 kJ portion of pizza). This study also revealed that these differences in expected satiety are preserved even when different standards are used (we compared a sweet and a savoury standard), and that measures of expected satiety have excellent test–retest reliability.

This approach to measuring expected satiety can also be used to quantify differences within a single food category. For example, in a subsequent study we showed reasonably large (2–3-fold) differences in the expected satiety of eight snack foods(19). However, a disadvantage of the method of constant stimuli is that it requires participants to provide many responses. This can be burdensome, especially when many foods are being tested in a single test session. In response, we have also developed a measure based on a ‘method of adjustment’(20). In this paradigm, participants are shown a picture of a food portion on a computer screen. Next to this picture they are shown a fixed portion of a different food (the standard). Using custom-written software, participants change the size of the first portion using a keyboard response. Pictures of larger or smaller portions are loaded with sufficient speed that the change in size appears ‘animated’. To quantify expected satiety the participants are told to adjust the size of the first portion until both foods are expected to stave off hunger for the same period of time. The selected portion size is then recorded, along with information about its energy content and macronutrient composition. As with the method of constant stimuli, by keeping the standard constant, expected satiety can be compared across a range of different foods.

A related concept is ‘expected satiation,’ the extent to which foods are expected to produce a feeling of fullness (immediately after they have been eaten) when compared on a kJ-for-kJ basis. As with expected satiety, expected satiation can be measured using either a method of constant stimuli or a method of adjustment. And, as with expected satiety, large differences are found across foods(17,20), and subtle differences can be detected in foods that share similar characteristics(21). The prospect that foods can differ markedly in their expected satiation and expected satiety is a very recent discovery. Nevertheless, as we shall see, we already have evidence that these differences are important because they are an excellent predictor of the energy content of food that ends up on our plate.

Palatability, expected satiety/satiation and the energy content of self-selected meals

Using a method of adjustment we can also obtain precise measures of a momentary ‘ideal’ or ‘prospective’ portion size. Participants are presented with a single food and then told to manipulate the size of the portion to correspond with ‘ . . . the amount of this food you would select to consume right now’(17,21,22). Since the foods are photographed, the technique is highly portable and requires no food preparation. Data can be combined across foods to estimate the energy content of a nominal meal at any given moment, and this estimate can be obtained several times during an inter-meal interval. This is particularly useful when assessing the effects of a specific intervention (e.g. physical exercise) on short-term energy balance. Of course, this measure can also been used to explore responses to specific foods. Using these responses, we can begin to piece together reasons why self-selected portions of some foods tend to be smaller than others (in kJ), even at the same type of meal (breakfast, lunch and dinner).

We make decisions about portion size every day: how much breakfast cereal to pour into a bowl in the morning, whether to have a large or a small sandwich for lunch and whether to select a side dish to complement an evening meal. In any given decision we may be motivated by the need to feel replete and to stave off hunger. However, our selection might also reflect a desire to enjoy and to savour the hedonic characteristics of a meal. It is often argued that we consume more of the foods that we like(23). Indeed, the palatability of energy-dense food is generally regarded as an important factor that contributes to overconsumption and weight gain(24). One reason why palatability is seen as an important determinant of energy intake is that meal size changes when it is manipulated under controlled conditions(25). But is palatability the *most* important driver of food intake? To address this question requires a systematic manipulation of several contributory factors across a range of everyday foods (i.e. excluding unpleasant foods that would not normally be purchased). In this context, the critical question is whether variance in energy intake (across meals) is explained primarily by variance in palatability (across meals) or by one or more other factors. Building on our finding that foods have very different expected satieties(18), my colleagues and I decided to explore the relative role of palatability, expected satiety and expected satiation as determinants of the energy content of self-selected meals. In one study, we obtained palatability ratings for eight commonly consumed snack foods during lunchtime(19). For each food, we also elicited a measure of expected satiety and a measure of ‘ideal’ portion size, at lunchtime (participants were told to assume that they were going to consume only one of these snack foods and that they would then receive no other food until dinnertime). Across test foods, palatability and expected satiety were equally good predictors of the energy content of ideal portion sizes. In this study, we also considered individual differences in the relative importance of palatability and expected satiety. Restrained eaters tended to be especially influenced by expected satiety, perhaps because this group routinely selects food based on its capacity to generate satiety. Interestingly, we found a similar pattern in individuals with a higher BMI. These data were obtained from a sample with a relatively narrow range of BMI, using a small number of snack foods. Therefore, we remain circumspect about the broader implications of these findings. Nevertheless, the prospect that researchers can quantify the relative importance of expected satiety (and other predictors) is exciting, because it suggests that we can begin to identify individual differences in the way that people make decisions about food and food portions.

In the second study, we compared the independent role of palatability and expected satiation(20) using a wide range of different foods (seventeen in total). Again, participants provided measures relating to decisions around lunchtime. These time ratings of palatability (expected liking) were a very poor predictor of the energy content of self-selected ideal portion sizes (r 0·06). By contrast, expected satiation was an extremely good predictor (r −0·80). Specifically, foods that had high expected satiation (compared kJ for kJ) were selected in smaller portions (kJ). When interpreting this finding, it is important to note that, consistent with previous findings(18), expected satiation differed considerably across foods (by about 400 %). By contrast, differences in the palatability of the test foods were modest. This probably reflects experience outside the laboratory; very few foods in our shopping baskets are low in palatability, in part, because food manufacturers design products with this characteristic in mind. This means that, when compared directly, differences in expected satiation swamped and outweighed any effect based on differences in palatability. These studies represent the first of their kind to directly compare expected satiety and expected satiation with palatability as predictors of the energy content of self-selected foods. Of course, these findings relate only to self-selected portions, not food intake.

Nevertheless, as we shall see, self-selected portion sizes are likely to correlate highly with actual meal size. Further data are needed to demonstrate that these findings are preserved across a range of meal and eating contexts, and in particular, when eating appears to occur in 'the absence of hunger'(26). Nevertheless, these findings challenge widely held assumptions about palatability as a primary determinant of meal size and they confirm that measures of expected satiety and satiation are interesting and merit further consideration.

A role for associative learning: introducing the expected-satiation 'drift' hypothesis

In several studies, my colleagues and I have found that measures of expected satiety and expected satiation are highly correlated (JM Brunstrom, M Wright, K Munford and J Bartlett, unpublished results) and that, kJ for kJ, we expect greater satiety and satiation from low-energy-dense foods(18,20). These findings are compatible with a number of studies showing that energy intake is reduced when low-energy-dense foods are consumed(8,27–29). Observations of this kind are important because they suggest that satiation might be determined by the volume (energy density) of food that is consumed rather than by its energy content or macronutrient composition. Based on these findings, we hypothesised that this effect of volume on satiation might be anticipated and reflected in decisions about portion size, before a meal begins.

To explore this idea, we used the method of adjustment to elicit separate 'perceived volume', expected satiation and ideal portion-size judgments, for nine different main-meal foods(17). Using a variance partitioning procedure(30), we found that expected satiation explained 74·8 % of the variance in the energy content of self-selected portions (*r* 0·86). Of this, 31 % was shared with perceived volume, indicating that volume influences portion-size decisions by moderating expectations around satiation. However, an even larger proportion of the variance (43·8 %) was found to be 'unique' and unrelated to the perceived physical dimensions of the foods. This shows that expected satiation is not a simple proxy for perceived volume, that foods of equal volume are not expected to be equally satiating, and that judgments relating to expected satiation are not based on a simple heuristic along the lines 'if it is larger then it should be more satisfying'.

So what explains this large portion of unique variance that accounts for the relationship between expected satiation and self-selected portions? In human subjects, food is emptied into the duodenum for absorption at a rate of only about 10 kJ/min(31). This greatly constrains the opportunity for physiological adaptation and the detection of energy as a meal proceeds. One way to overcome this problem is to use prior experience to moderate intake. Indeed, the notion that meal size reflects a learned anticipatory response was first proposed over half a decade ago(32). Specifically, researchers have suggested that satiation is under learned control, and that it is moderated by an association that forms between the sensory characteristics of a food and the sensing of nutrients some time after a meal has been ingested(33,34). Unfortunately, in human subjects, evidence for conditioned control of meal size has been equivocal(34,35) and the evidence that does exist tends to be found in studies involving children(35). In a recent article, I suggested that 'flavour-nutrient associations' might be readily formed. However, rather than influencing satiation towards the end of a meal (as demonstrated in free-feeding animal behaviour), they might moderate the selection of portion sizes, prior to meal onset(34). I suspect that the unique variance that relates expected satiation to portion selection is based on learned associations of this kind. Recently, several findings have emerged that support this interpretation.

In one study, my colleagues and I demonstrated effects of flavour-nutrient learning on expected satiety under controlled conditions(36). Participants sampled a highly novel dessert and then assessed its expected satiation. They then consumed an otherwise identical low (954 kJ)- or a high (2378 kJ)-energy-dense version of the dessert. At a subsequent test session expected satiation was higher, but only in participants who consumed the high-energy-dense version during training. In other studies, we simply explored the effects of everyday familiarity with a food. Consistently, familiarity appears to be associated with higher expectations. Across foods, expected satiety is higher in foods that are ranked as more familiar and in foods that are consumed on a regular basis(18). Similarly, food-frequency effects are observed in expected satiation, both across foods, and in individuals who were more or less familiar with a single 'candidate' food (sushi)(37). Differences in expectations are found in individuals who have and who have not consumed a food in the past. Thus, consistent with our controlled study, it would appear that learning is relatively rapid and that it has the potential to occur even after a single exposure to a new food. In addition to general exposure, it would appear that shifts in expectations are especially evident in individuals who report having previously 'eaten a food to fullness'(38). Thus, changes in expectations are likely to be promoted by signals that are present towards the end of a meal. Snack foods tend to be consumed in small portions and rarely to satiation, which might explain why these foods tend to have very low expected satiety (compared with other foods kJ for kJ)(17).

In a further study, we covertly manipulated the energy density of an otherwise familiar food (spaghetti Bolognese) and served it to participants in either a regular or low-energy-dense version over five consecutive days(21). Participants in the reduced energy-dense condition reported a decrease in liking for the test food, whereas liking in the standard condition remained constant. By contrast, both expected satiation and expected satiety remained similar and constant across conditions and test sessions. In a similar study, Hogenkamp *et al.*(39) manipulated the energy density of a soup and served it over 4 d. Again, expected satiation remained unchanged after repeated exposure. However, in a second experiment, these researchers took a single measure of expected satiation, for both the high- and low-energy-dense soup, and several other commonly consumed soups. The data showed that their participants had a pre-existing capacity to discriminate between the soups based on the satiation that they were expected to confer.

This finding is important, because it suggests that the initial failure to show shifts in expected satiation (over 4 d) resulted, not from incapacity to learn flavour-nutrient relationships, but from incapacity to relearn pre-existing associations based on prior experience. Indeed, their data suggest that these associations are reflected in a highly refined capacity to discriminate between foods, and that this is evident, even in foods (soups) that are ostensibly very similar.

Across published and unpublished studies a pattern is emerging; familiarity increases expected satiety and expected satiation. However, when participants are presented with an otherwise familiar food that has a lowered energy density, expectations remain unchanged. Recently, my co-researchers and I proposed a hypothesis based on a hitherto unexplored underlying disposition(37).

From a foraging perspective, it would seem prudent for an animal to assume that novel foods are low in energy density and then to learn otherwise. This strategy limits foraging for foods that turn out to be of little (nutritive) value. Since foragers are unlikely to ever encounter ‘diet’ or ‘lite’ varieties it makes little sense to acquire the capacity to downgrade or lower expectations associated with a food source. Accordingly, shifts in expected satiation are much more likely to occur in one direction (expected satiation will tend to increase). This ‘expected satiation drift’ hypothesis remains to be tested formally. (Note that other learned responses to low-energy-dense foods have been observed previously(40)). Nevertheless, this idea merits consideration, because it follows that newly encountered weight-loss or weight-management foods will have a higher expected satiation if they have been consumed previously in regular energy-dense varieties. Because these expectations are resistant to lowering, they will endure over time, which may promote a continued loyalty towards particular low-energy-dense products and foods.

Are ‘food expectations’ really important?

The theoretical relevance of expected satiety and expected satiation hinges around two assertions. First that the amount of food on our plate at the beginning of a meal predicts the amount that is consumed. Second, people actively plan their meal size prior to meal initiation.

In relation to the first of these (a relationship between initial portion size and meal intake), the evidence is reasonably consistent. In a variety of contexts, the amount of food that is consumed is highly dependent on the amount that is served or that is available at the outset(8,41,42). In terms of evidence relating specifically to ‘plate cleaning’, the extant literature is modest, making it difficult to compare across cultures and socio-economic groups. Nevertheless, in cases where this behaviour has been measured, it is found to be commonplace(43,44). In a recent study, we asked 764 participants to report their experience at a previous meal(45). Using a structured questionnaire, we found evidence for plate cleaning in 91 % of meals, confirming that this behaviour occurs very often, at least in a sample recruited from south-west England.

The second assertion is that people actively plan their meal prior to meal initiation. Intuitively, this would seem highly likely. However, very few studies have actually quantified this activity. In our structured questionnaire, we also probed memories of meal planning prior to meal onset. When plate cleaning occurred, most participants (92 %) reported planning to consume the entire portion from the outset(45). This close correspondence between plate cleaning and meal planning was observed, regardless of who selected the portion, meal location and meal type (breakfast, lunch and dinner). In contrast, experience within a meal appeared to be less relevant. Many participants (28 %) reported that they ate beyond satiation (often to avoid food waste) and 57 % indicated that they could have eaten more at the end of the meal. Interestingly, in another large-scale study, researchers explored predictors of food consumption in military personnel. Across a range of foods, perceived ‘fillingness’ was the best predictor of food choice, better than the macronutrient composition or even the palatability of the foods(46). Together, these findings suggest that planning and subsequent plate cleaning tend to co-occur, and that within-meal experience may be a relatively poor predictor of the amount of food that is consumed in a meal.

Of course, meal size is likely to be influenced by many different factors. Moreover, their relative importance will depend on the nature of the food, the specific meal and the social context within which it is consumed. Considerable control can be expressed when we prepare a meal using raw ingredients, both in terms of the foods that are selected and the amount that eventually appears on a plate. By contrast, in a restaurant, portions tend to be determined by a chef. Nevertheless, opportunities still exist to plan and express control over intake. For example, we might choose to avoid specific menu items that we believe will fail to satisfy or deliver satiety. Alternatively, on occasions when very large portions are served we might decide from the outset how much of the meal we are going to consume. In future, it would be fascinating to explore individual differences in the process of planning, the tendency towards plate cleaning, and whether particular strategies represent a risk factor for overweight and obesity. Research of this kind might also focus on the broader expression of these behaviours, both in family members and in different social contexts.

Concluding remarks

A general observation from studies exploring expected satiety and satiation is that participants find the process of selecting and discriminating between portion sizes to be effortless and intuitive. This seems to coincide with everyday experience. Decisions about food often (but not always) feel habitual. However, it is important to recognise that simply because a decision or behaviour ‘feels’ simple or effortless does not mean it is necessarily governed by a simple rule or that the underlying cognition is uncomplicated. Evidence from a broad literature on implicit cognition and decision-making reveals that the capacity to explain or ruminate around the decisions that we make is often unrelated or even inversely related to the number of factors that are integrated in the underlying process[47,48].

The average 21-year-old will have consumed approximately 23 000 meals in his or her lifetime. Therefore, most of us should be considered experts at eating. This experience gives us ample opportunity to learn and acquire expectations about the consequences of consuming different foods and it is for this reason that the process of portion selection becomes so highly practised and rehearsed, and why we are able to demonstrate subtle discrimination between foods and portions sizes based on their expected satiety and expected satiation. A universal and highly refined ability of this kind is unlikely to develop unless it serves an important role in the regulation of energy intake.

In summary, food intake can be controlled by processes that operate either before a meal begins or while it is being eaten (or both). Measures of *ad libitum* eating can tell us a great deal about within-meal experience. However, in isolation they provide an unbalanced and potentially distorted understanding of dietary control. A challenge for the future will be to unpick the cognitive structures that underpin the decisions that we make about food and portion size, and then explore how these combine with events that take place as a meal proceeds. In this way, we will gain a better understanding of the controls of meal size in human subjects.

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