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Expected Satiety: Application to Weight Management and Understanding Energy Selection in Humans

Ciarán G. Forde · Eva Almiron-Roig · Jeffrey M. Brunstrom

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Abstract Recent advances in the approaches used to quantify expectations of satiation and satiety have led to a better understanding of how humans select and consume food, and the associated links to energy intake regulation. When compared calorie for calorie some foods are expected to deliver several times more satiety than others, and multiple studies have demonstrated that people are able to discriminate between similar foods reliably and with considerable sensitivity. These findings have implications for the control of meal size and the design of foods that can be used to lower the energy density of diets. These methods and findings are discussed in terms of their implications for weight management. The current paper also highlights why expected satiety may also play an important role beyond energy selection, in moderating appetite sensations after a meal has been consumed, through memory for recent eating and the selection of foods across future meals.

Keywords Expected satiety · Portion selection · Food intake

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C. G. Forde (✉)
Clinical Nutrition Research Centre, Singapore Institute for Clinical Sciences, 14 Medical Drive, #07-02, Singapore 117599, Singapore
e-mail: Ciaran_Forde@sics.a-star.edu.sg

E. Almiron-Roig
MRC Human Nutrition Research, Cambridge, UK
e-mail: Eva.Almiron-roig@mrc-hnr.cam.ac.uk

J. M. Brunstrom
Nutrition and Behaviour Unit, School of Experimental Psychology, University of Bristol, Bristol, UK
e-mail: Jeff.Brunstrom@bristol.ac.uk

Introduction

In recent years significant advances have been made in our understanding of the cognitive processes that inform food and portion selection, and the relative interplay between food choice, consumption and post-meal satiety. Much of this research has focused on the development of approaches to quantify consumer expectations for the fullness (expected satiation) and the absence of hunger between meals (expected satiety) that different food and beverage products are expected to deliver [1]. Comparing these expectations across foods on a calorie for calorie basis has enabled a step-change in our understanding of energy selection and post-meal satiety, and has challenged the way we think about meal size control. The current review summarises these developments including the application of expected satiety measures to better understand energy selection, post-meal satiety, and weight management, and proposes some directions for future research.

Approaches Used to Measure Expected Satiety

The various approaches that have been used to compare expectations about fullness and satiety in foods and beverages are summarised in Table 1. Attribute scales including visual-analogue scale (VAS) [4, 10] and category scales have been applied to measure subjective expectations of fullness and satiety. Earlier approaches to quantifying expectations were based on this approach (e.g. [8]) or the use of a 20-point category scale (e.g. [11]) and followed the same format as currently validated VAS questions assessing post-preload fullness [17]. These scales have now been integrated in different expected satiety measurement tasks with sufficient sensitivity [2, 7, 10, 18]. Category scales have also been applied to measure expectations of fullness and satiety (see Table 1) and in one study measuring the satiating strength of sandwiches, the

Table 1 Summary of methods used to measure expected satiation and expected satiety

Method	Outcome measure	Test foods	Procedure/used as	Validity/sensitivity	Reference
100 mm VAS ("How filling do you think this drink is?" Not at all; Extremely)	Expected satiety rating	Picture of 400 ml (men) or 300 ml (women) labelled, sugar-sweetened/non-caloric drink/ yoghurt shown and then served for breakfast; Tasting involved	With other VAS for wanting and liking as part of satiety trial	Able to detect significant differences in ES between drinks and yoghurts	Griffioen-Roose et al., 2013 [2]
100 mm VAS ("How filling is this soup"? Hardly filling; Very much filling)	Expected satiation rating	Tomato soup consumed in small, large or unrestricted sip size, ad lib; Tasting involved	As part of sensory evaluation test (first session only) in eating rate study	Not determined	Bolhuis et al., 2013 [3]
100 mm VAS ("How filling would you expect this portion of this food to be?" Not full at all; Extremely full)	Expected satiation	Pictures of 200 g main meal portions (overall 35 food items shown); Tasting involved	With VAS measures for sensory evaluation in oral processing study	Validated with trained panel. Correlates with food intake in laboratory study	Forde et al., 2013 [4, 5] Arboleya et al., 2013 [6]
100 mm VAS for "expected fillingness" (Anchors: Not at all; Extremely)[a]	Expected satiety/satiation	320 g portion of fruit-flavoured yoghurt drink; Tasting involved	As part of sensory evaluation test programmed on SIPM	Sensory test validated in SIPM previously (Yeomans, 2000)	Yeomans et al., 2014 [7]
100 mm VAS for "filling" (anchors: Not at all filling; Extremely filling)	Expected satiety	20 savoury or sweet snacks high in fat or carbohydrate; Tasting involved	With other sensory VAS measures in predictors of satiety study	Able to detect significant differences in fillingness across foods.	Green & Blundell, 1996 [8]
100 mm VAS for "filling" (anchors: Not at all; as filling as I have ever experienced)	Expected satiation	450 g of carrot soup; tasting involved	As part of sensory evaluation programmed in SIPM, in MSG study	Sensory test validated in SIPM previously (Yeomans, 2000)	Masic & Yeomans, 2013 [9]
100 mm VAS ("How full do you think you would be after consuming this amount of food/drink?" Not full at all; Extremely full)	Expected satiating power (expected satiation)	8 commercial snacks and desserts incl. energy beverages; Tasting NOT involved	As part of portion size evaluation trial with real foods (no tasting involved)	Piloted amongst 20 men; able to detect significant differences in ES across test foods	Brogden & Almiron-Roig (2010) [10]
20-point category scale (1=weakly satiating; 20=strongly satiating)	Satiating strength rating	9×15 cm pictures of 2 slices of bread with spreads of varied macronutrient composition	Part of a home interview	High construct validity against satiating time (r(14)=0.98; p<0.01)	De Graaf et al., 1992 [11]
Method of adjustment (the portion of a food is changed until it matches the comparison food)	Expected satiation across portion sizes; Prospective/ desired portion size (compares on a calorie-for-calorie basis)	Large range of sweet and savoury snacks; some dishes and desserts; Tasting NOT involved	With our without method of constant stimuli; used in children (Hardman et al. 2011); studies to test the effects of food-cue reactivity; familiarity; nutrient status & variety on portion choice	Validated against actual food intake (Wilkinson et al., 2012)	Brunstrom et al., 2009a; 2009b [12, 13]; Ferriday & Brunstrom, 2008 [1]; Hardman et al., 2011 [14] Wilkinson et al., 2012 [15]
Method of adjustment adapted (test food weighed on participant's hand and compared to standard food on screen)	Expected satiety	125 g of strawberry yoghurt; Tasting NOT involved	As part of a container weight evaluation trial with real foods;	Able to detect differences in ES across test foods differing 75 g in weight)	Piqueras & Spence, 2012 [8]
Method of constant stimuli (pictures of varied portions of foods are compared	Expected satiety across foods (compares on a calorie-for-calorie basis i.e. the test	Large range of sweet and savoury snacks; main dishes and desserts; Tasting NOT involved	With our without method of adjustment	Validated against actual food intake (Wilkinson et al., 2012)	Brunstrom et al., 2008; 2009; 2014 [1, 12, 13, 16•]

Table 1 (continued)

Method	Outcome measure	Test foods	Procedure/used as	Validity/sensitivity	Reference
against a fixed portion of a standard food)	food to deliver the same satiety as the standard food)				
Method of constant stimuli adapted using real test food	Predicted energy (kJ) to suppress anticipated hunger after the imagined consumption of test food	320 g portion of fruit-flavoured yoghurt drink; Tasting involved	Before VAS questionnaire including "Expected fillingness" rating (see above)	See Method of constant stimuli	Yeomans et al., 2014 [7]
Tick question for Fullness ("which of the 2 yoghurts you expect to make you feel fuller? A; B; equally)	Expected satiation	125 g of strawberry yoghurt; Tasting involved	With perceived density question before the fullness tick	Not validated	Piqueras & Spence, 2012 [8]
Time of return of hunger	Satiating time (time in units of 15 min) which would pass between eating the foods on the picture and the subsequent return of feelings of hunger	9×15 cm pictures of 2 slices of bread with spreads of varied macronutrient composition	Part of a home interview	High construct validity against satiating strength rating (r(14)=0.98; p<0.01)	de Graaf et al., 1992 [11]

[a] Wording for the VAS question not specified

category labels showed high construct validity against time to return of hunger [11].

Not all approaches have compared expected satiety across foods in a standardised way that accounts for volume, weight or energy content, making it difficult to compare findings for specific foods across studies. Recently this standardisation has been applied to enable comparison across foods on a calorie for calorie basis [1, 2, 10, 12]. The two most widely used methods incorporate psychophysical procedures (method of constant stimuli and method of adjustment) and foods are compared directly on a calorie-for-calorie basis. Figure 1 shows an example of a 'matched fullness task' which is based on the method of adjustment and is used to quantify expected satiation. These approaches have also integrated measurement of expected liking, ideal portion size and familiarity, and in combination, they provide a comprehensive assessment of beliefs about specific foods. Computerised methods for assessing prospective portion size (see [16•] for review) are highly sensitive and can be used across or within foods. This approach has been widely applied in various studies including food-cue reactivity; familiarity; nutrient status and food variety studies, covering an extensive range of food items, meal types and age ranges (see Table 1 for references). These approaches can also be used to measure prospective self-selected portion sizes and can be combined with more traditional measures of food intake. Importantly, computer-based psychophysical measures of expected satiety and expected satiation are very good predictors of the amount of food that people physically self-select and then consume. A recent study has demonstrated that expected satiety is an excellent predictor of meal size (r=0.523), and a comparatively better predictor than rated hunger (r=0.016), expected liking (r=0.328), and a trait measure of dietary restraint (r=0.01) [15]. In previous research on expected satiation using 'fillingness' scales, responses did not correlate well with food intake in between-subjects studies [8]. Nevertheless, in a within-subjects design they predicted energy intake and the delay in the return to

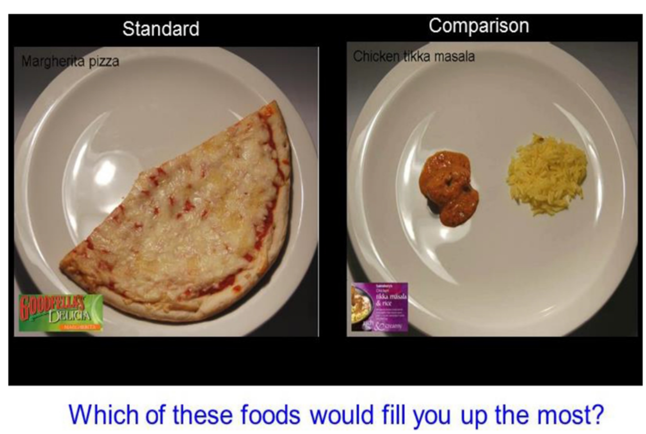

Fig. 1 A screen capture of a matched fullness 'expected satiation' task. (Image courtesy of Prof. Jeff Brunstrom)

hunger after eating [6]. These methods have also been adapted to incorporate real food stimuli instead of photographs [19].

Less sensitive measures of expected satiety (i.e. those generating non-continuous ratings) also exist such as tick questionnaires [19], and indirect measures based on prospective portion size consumption or portion estimates but these methods may involve further interpretation (Table 2). For example measures of habitual portion size may allow the detection of learned effects but some instruments may not be sensitive enough for certain food types such as applying a VAS to evaluate usual portion size of multiple-item meals [20, 21].

The methodology discussed above is based on the concept that specific learning mechanisms occur through our lifetime that allow us to learn how satiating a food will be without having to consume it or even taste it. It is still not known exactly how these links develop but fMRI has shown that synaptic adaptation may be involved in the learning process [26]. Expectations may also develop based on an association with specific changes in gut peptides [27], appetite sensations [28] and gastric processes [29].

What Do We Know About Expected Satiety and Expected Satiation?

Food Familiarity and Expected Satiety

Consumers are comfortable discriminating between foods based on their expectations of fullness and satiety, and responses are highly reliable [1]. Importantly, foods differ considerably in the satiety they are expected to deliver, when compared on a calorie-for-calorie basis by matching for underlying differences in energy density [1, 10, 12, 30]. Indeed, in one study fivefold differences have been observed [1]. Several studies report a relationship with energy density — foods with a high energy density (e.g. chocolate bars) tend to have lower expected satiety (compared calorie for calorie) [1, 13]. This indicates a broad disconnect between the energy content of a food and its expected satiety. Or, put differently, foods that are otherwise matched for weight can differ markedly in their energy content yet have the same expected satiety and expected satiation. This is important because these differences may contribute to the selection and overconsumption of highly palatable energy dense foods if people tend to rely on learned associations between the food and the fullness it will impart, rather than solely on the anticipated energy content of the meal [31].

Although energy density is a predictor of differences in expected satiety (calorie-for-calorie) it would be wrong to assume that at the time of consumption, foods are compared based solely on their visual appearance (volume in particular). In one study, measures of perceived volume failed to account for a large proportion of the variance in expected satiation across foods. This was taken as evidence that learning plays an important role [32]. Consistent with this proposition, novel foods are found to have lower expected satiation than familiar foods and expected satiety ratings have been shown to increase the more familiar a food becomes [1, 33–35]).

Expected Satiety as a Predictor of Energy Intake of Meals

The predictive validity of computer-based assessments of expected satiation has now been established [15]. In one study participants assessed the expected satiation of a range of foods and were then offered one of these foods in an ad-libitum test meal. Participants served themselves and ate until comfortably full. The initial computer-based measures of expected satiation were an excellent predictor of subsequent food intake, better than pre-meal measures of hunger, fullness, liking and reward, and a better predictor of individual differences in intake than measures of BMI and dietary restraint. This is important for energy-intake regulation since an estimated 86-92% of people will fully consume the portion they choose to serve themselves [36, 37]. The implication is that the key opportunity to control energy intake within a meal may be during the brief period of cognitive activity during portion selection, rather than during and towards the end of a meal with the onset of satiation [36–38].

The prevailing view is that people tend to eat more of the foods they like and previous research has shown that palatability can be manipulated to change meal size [39] and the onset of satiation [40]. However when the relative role of expected satiety and liking are compared systematically, expected fullness appears to be a stronger predictor of portion selection [12, 13, 15, 33]. One possibility is that a Western diet involves mostly palatable foods. Therefore, the range of variation in palatability is small relative to the contribution of large differences in expected satiety and expected satiation [12]. This suggests that an opportunity exists to reduce energy intake by encouraging the consumption of palatable foods that have high expected satiation. A further possibility is that expectations are more important when we are hungry rather than sated [10]. In particular, rather little is known about the role of expected satiety and expected satiation in decisions about desserts and this merits further study in the future.

Expected Satiety Is Learned and Can Be Used to Promote Post Meal Satiety

Measures of expected satiety and expected satiation are highly reproducible but may be modified and influenced by a range of visual, informational (e.g. labelling), and sensory cues. Expectations are learned over time and inform our memory for the meal. An important component of this learning is the strong association that is formed between a food's sensory properties and the satiation and satiety that it generates. When

Table 2 Indirect measures of expected satiety and expected satiation

Method	Outcome measure	Test foods	Procedure/used as	Validity/sensitivity	Reference
100 mm VAS ("How does the size of this serving compare to your usual portion?" A lot smaller; A lot larger)	Habitual portion size	Breakfast, lunch and dinner dishes; snacks; desserts and on the go 'meal deals'	Portion size estimation trials	Not sensitive for multiple unit foods or distinguishing meals from snacks	Kral, 2006 [20]; Almiron-Roig et al., 2013 [21]
100 mm VAS ("How much of another product do you think you would be able to consume after eating this amount of food?" None at all; A large amount)	Prospective portion size	16×11 cm picture of caffè latte; 7×5 cm picture of flapjack; Tasting not involved	Pilot study	Piloted amongst 20 male volunteers; less preferred than expected satiating power question (see	Brogden, 2009 [22]
Area of 3D model of pizza	Desired portion size	Extendible 15×13×3 cm cardboard model of cheese and tomato pizza	Food-cue reactivity trial	Able to detect significant associations between desired portion size and reactivity or impulsivity scores	Tetley et al., 2010, [23]
Satiety quotient; Satiety Index	Estimated satiety power based on actual food intake (rather than participant's beliefs) or reference foods	Wide range of foods	Based on intake measured in laboratory	SQ for predicts ad libitum energy intake in women	Green & Blundell, 1997 Drapeau et al., 2005 Holt et al., 1995 [24]
Visual meal creator (Vimec); portion sizes modifiable similarly to the method of adjustment	Desired portion size	17 main meal items	Validation study	Validated against VAS to test ability to predict food intake	Holliday et al., 2014, [25]

the sensory properties and eating behaviours of a wide range of food items were compared to their rated expected satiety, some sensory properties were highly correlated with expected satiety and ideal portion size [5]. For example, foods that require more chewing are consumed in smaller bites and have longer oral-residence time. Importantly, studies have compared eating behaviours associated with a range of different meals and shown that expected satiation is closely correlated with different types of eating behaviours (e.g. longer oral processing time) which also predict post-meal satiation [5, 41]. Research on sensory cues has demonstrated that subtle changes to the flavour and texture of drinks or yogurts can enhance expectations of fullness and have been shown to reduce feelings of hunger after a meal [42–46]. These findings highlight the possibility that sensory properties can be modified, not only to increase expected satiety but also post-meal satiety. In addition to sensory cues, beliefs about the amount of food consumed can also affect satiation. In one study, the expected satiety was manipulated by changing people's beliefs about the quantity of fruit added to a fruit smoothie [28]. This resulted in stronger perception of satiety despite the energy consumed remaining the same. Further studies have used labels with product descriptions such as "fuller for longer" which have been shown to increase both expected satiety and actual satiety when participants consumed the same yogurt [47]. In one such study, researchers used a re-filling bowl to manipulate the visual cues and beliefs about the quantity of soup consumed in a meal [48]. When participants were led to believe that they had consumed a larger meal this produced a relative reduction in hunger that was evident two and three hours into the inter-meal interval. Importantly, participants believing they had consumed a larger portion expected the soup to deliver greater satiation at a subsequent test session.

Conditioning greater expected satiety is important because it impacts portion selection and post-meal satiety. However, it also affects memory for the meal, which is known to affect subsequent food intake. Studies have demonstrated that thinking about food [47] or about the meal that has been consumed, decreases food intake and in some cases influences post-meal satiety by increasing circulating levels of satiety hormones; and has an impact on the foods selected at the next meal [27, 29, 49]. Expectations of fullness and satiety influence energy intake at the beginning of the meal by informing portion selection but they also play an important role in controlling energy intake at a subsequent meal. Specifically, expectations may influence 'memory for recent eating,' a process that is found to moderate food intake from meal to meal [50]. Simply thinking about foods, whether recently consumed or not, seems to have a stable and robust impact on later food choice and intake [49, 51]. However, thinking about the expected satiety of a familiar food is not sufficient to change formed perceptions about portions [1], which suggests that habitual behaviours and subjective norms also have a role to play.

The fact that a meal's post-ingestive consequences can be altered by memory and learning, in addition to endocrine and absorptive effects, indicates a need to expand beyond a traditional focus on within-meal events and drivers of satiation such as energy density or macro-nutrient content. Further research on the factors that moderate expected fullness for a food are important variables for inclusion in studies aimed at better understanding the psychobiology of satiety and short-term controls of energy intake. If expected satiety can predict energy selected and subsequent satiety derived based on our learned associations, we may ask whether it is possible to reduce energy and still sustain the fullness perceived from the meal. This idea was explored in a five-day intervention with a lower energy version of a spaghetti Bolognese [52]. The findings show that expectations about the satiating properties of the dish did not decrease over time. However, liking ratings steadily decreased, indicating that the decrease in energy attenuated the hedonic response. These findings suggest there could be an opportunity to optimise hedonic properties and reduce the energy content of a food, by capitalising on established and robust learned associations between a food's fullness independently of the underlying energy content.

Directions for Future Research

The recent development of methods to quantify the expected satiety of foods is important because it has revealed marked differences between foods [1] and in a consistent manner across research groups [10, 12, 30]. Calorie for calorie some foods are expected to deliver several times more satiety than others. This work has also shown us that people are able to discriminate between different varieties of the same food (e.g. soups) suggesting considerable sensitivity and specificity [30]. From the perspective of food-product development, assessing these beliefs can be very helpful, especially in foods that are designed to confer benefits for weight management [5, 30, 43, 53–55]. However, it is also important to remember that expected satiety is not a physical property. Although expected satiety 'values' are often attributed to specific foods, these tend to be based on aggregated opinion. We have personal beliefs and these are based on a lifetime of exposure to different foods in a variety of contexts. Recent work has explored expectations in children [14] and in patients with anorexia nervosa [56]. However, much more needs to be done to understand individual differences. Obvious targets involve comparisons with obese individuals and with other groups that exhibit aberrant eating behaviour.

In addition to the above, two other areas merit attention. First, there is still considerable uncertainty about how expected satiety and expected satiation influences food choice. Previously, two studies have quantified the rewarding characteristics of foods that differ in their expected satiety [13] and expected satiation [12]. Critically, participants judged the value of different foods that were matched for their energy content. Those that had higher expected satiety and satiation were clearly favoured. Indeed, in decisions around lunchtime, expected satiation was a more important driver of choice than differences in rated pleasantness [12]. By contrast, in studies of non-human animals, satiety is not particularly rewarding and foods tend not to be selected on this basis. Indeed, gastric balloons and exogenous administration of physiological doses of CCK are potentially aversive [57], although we note that low levels of CCK do appear to condition food preferences in rats [58]. The implication is that food reinforcement is governed largely by the post-ingestive nutritive effects of food rather than by its capacity to generate satiety and inhibit further food intake [59]. The reason for this apparent discrepancy across species remains unclear. One possibility is that our choice of food reflects a capacity to anticipate inter-meal interval and then to select foods that provide a sustained reduction in hunger over this period. Either way, we suspect that expectations play an important yet largely unexplored role in food choice.

Second, there are a number of questions relating the acquisition of post-ingestive expectations that remain unanswered. In particular, it is remarkable that we have a capacity to estimate the satiety and satiation associated with so many different types of foods, including different associated brands, varieties and so on. Hunter gatherers are unlikely to encounter the enormous variety that is evident in a typical Western diet [60]. One possibility is that this complexity forces the use of heuristics along the lines "it's big so it must be filling". There is already some evidence that perceived volume or perceived weight play a key role of this kind [19, 32], especially in foods that are consumed infrequently [14]. What remains unclear is whether a highly complex dietary environment encourages the use of this type of 'dietary heuristic' and whether this compromises our capacity to estimate appropriate meal size. In relation to this idea, we note that disrupting the ability of a rat to predict the nutritive consequences of a food based on a flavour cue can impair subsequent compensation for energy, which is associated with an increase in bodyweight over time [61]. It remains unclear whether a similar process promotes 'prediction error' in expectations and indeed whether a critical developmental period exists during which dietary expectations tend to be learned.

We also should remember that our capacity to anticipate satiety and satiation serves a purpose. Expectations play an essential role in the control of meal size and it is in this broader context that the concept of expected satiety has become appreciated. In humans, as in other omnivores, post-ingestive consequences must be anticipated during or in advance of eating. This is because first, we do not have constant access to food, and second, food drains from the stomach too slowly for appreciable detection of energy during a meal. Consistent with this idea, direct nasogastric infusion of nutrients produces relatively poor satiation [62] and this is especially the case when the infusion is covert [63]. These studies tell us that knowing what and how much we have just eaten is essential in moderating how much we are going to eat next. This idea is consistent with the observation that distraction decreases satiation [64] and increases meal size [65], and with the literature on 'memory for recent eating' that we have reviewed briefly above. Similar processes operate in non-human animals. Food intake is governed by forms of learned inhibition that are triggered by gustatory cues while eating [66–68]. Arguably, in humans, this anticipatory effect operates at a more conceptual level and is detached from the meal in that control is expressed before eating begins rather than during and towards the end of a meal. In other words, rather than relying exclusively on exposure to the oro-sensory characteristics of a food we capitalise on a capacity to plan our meal size in advance. This idea is consistent with recent evidence that plate cleaning is extremely common (see above) [36, 37] and that expected satiety is an excellent predictor of food intake [15]. Complex representations are formed and these enable planning, preparation and the selection of portion size. As such, the ability to anticipate and to plan may supersede other within-meal cues that otherwise play a role in the control of meal size in other animals. It is in this context that expected satiety should be regarded as a critical component of dietary control and in this context that we should seek to understand whether expectations play a role in overeating and obesity.

Finally, we suspect that the satiation and satiety that is expected from a food will also depend on context. In some cultures rather less food is consumed at breakfast than at dinnertime and this is reflected in decisions about appropriate portion. It is also common to see certain foods consumed only at certain times of day (breakfast cereal tends to be consumed at breakfast whereas a hot soup or fish dish is not). Expectations may be affected by these dietary patterns — the post-ingestive effects of a bowl of breakfast cereal may be very obvious at breakfast but more difficult to predict as an evening meal. Again, if correct, this suggests that expectations reflect a learned anticipation of the effects of consuming a particular food in a particular context. It remains unclear how this learned integration takes place and work on this topic could provide further insight in this rapidly developing area of research. In particular, it might be instructive to consider the specific process by which we adapt to a novel food. One possibility is that our initial assessment of a novel food is guided largely by its basic oro-sensory characteristics. In this context, sweetness and viscosity may be especially important because they correlate (albeit moderately) with the energy density of food [69]. However, over time, our estimates become refined and reflect a transfer of control from sensory stimulation to responding based on recognition of a 'configural stimulus' that comprises the unique combination of sensory features and post-ingestive effects that define a specific food.

Conclusions

In closing, we note the potential for these ideas and observations to be applied in a clinical setting and/or impact public health. For example, gastric bypass and gastric banding can have a dramatic impact on food preferences [70, 71], and alters the experience of fullness and meal pattern [72]. An opportunity exists to quantify and characterise changes in expected satiety and ideal portion size as a patient adapts to the effects of surgery. This kind of analysis might tell us something fundamental about dietary learning. However, it might also form the basis for a prognostic tool to evaluate dietary adjustments that signal the likely long-term benefits of surgery.

It is also important to understand the impact of specific dietary interventions or strategies on expected satiety and expected satiation. For example, restrained eaters and dieters are often exposed to low- or reduced-energy commercial products. In one study the effect of repeated exposure to a low energy-dense spaghetti Bolognese was explored over five days [52]. Over this period, liking for the meal decreased (relative to a regular energy-dense version). However, expected satiety and satiation remained constant. This appears to be one of the few studies to track changes in beliefs after exposure to an otherwise familiar reduced energy-dense food. (Note that this process has been explored in rodents and it is sometimes referred to as the 'missing calories effect' [73]). In the longer term the effects of exposure to a range of 'diet' varieties remains unclear. At the very least, this kind of exposure probably increases dietary variability and we have already speculated that this might compromise dietary learning. We also see potential application of these ideas in the promotion of healthy dietary choices. Many countries require food manufactures to provide information about the macronutrient composition and caloric content of food products. The assumption here is that this information can be assimilated and then used by the consumer. After reviewing the literature we conclude that satiety and satiation may be more meaningful and intuitive constructs than terms that refer to energy content (e.g. 'kcal per 100 g'). Since foods differ considerably in their expected satiety and satiation (kcal for kcal), an opportunity exists to consider ways to translate the potential impact of nutrition education or information systems (i.e. dietary labelling) that recognise and highlight differences on the basis of expected satiety. For example, one approach might take the form of a dietary intervention that reduces energy intake by promoting a greater awareness of the relationship between expected satiety, portion size choice and energy intake. Measures of expected satiety might be taken to quantify the impact on energy reduction over time; to establish whether a person's learned association between the fullness they expect from a certain food changes through repeated exposure to a lower energy version of the food. Central to this approach is the need to move beyond treating expected satiety as a property of a food and to recognise it as a measure of an individual's learned association between its sensory properties and previous experience of its post-ingestive effects. This is the process that governs portion selection and food intake. Therefore understanding the underlying mechanism may hold the key to efforts aimed at reducing energy intake and more broadly understanding the aetiology of obesity.

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Compliance with Ethics Guidelines

Conflict of Interest Ciarán G. Forde, Eva Almiron-Roig, and Jeffrey M. Brunstrom declare that they have no conflict of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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