ABSTRACT: Satiation, the processes leading to termination of a meal, and satiety, the state of inhibition over eating after a meal, both arise through the integration of cognitive, sensory and post-ingestive signals arising from consumption of foods and drinks. Although signals arising from nutrient ingestion are important, especially for satiety, both satiation and satiety are influenced by more cognitive aspects of the consumer experience. Recent research in particular highlights the importance of expectations about the likely effects of consumption and memories of effects of related products as elements of both satiation and satiety. This brief review assesses some of these psychological influences and discusses their implications for effective product development.

KEYWORDS: Expectancy, satiety, satiation, learning.

DEFINING SATIATION AND SATIETY

The motivational processes controlling appetite involve a complex interaction between factors promoting and enhancing intake, and factors that lead to the decision to stop eating and which subsequently inhibit further meals. This review concentrates on these latter components. Satiation has been defined as the process that terminates eating within a meal (1), and which consequently influences the size of meals and snacks. Satiety has been defined as the state that occurs after eating, and inhibits further eating, which influences the frequency of meals and snacks. Both satiation and satiety involve a complex interaction between cognitive, sensory, post-ingestive and post-absorptive signals generated by the ingested food or drink, and are elegantly represented by the “satiety cascade” (Figure 1), the notion that the relative importance of these different cue types varies over time from the point at which food is ingested. In brief, the cascade model views satiation primarily as a consequence of habit, expectation, oral-metering and sensory experience, with less influence of post-ingestive signals since many of these signals only appear after a meal has ended. Early stages of satiety are more influenced by the consequences of ingestion, especially gastric factors and hormones such as CCK, but again, as highlighted below, these are also strongly influenced by cognitive and sensory cues. The later stages of satiety include a variety of physiological influences, including release of specific satiety-hormones such as PYY and the generation of nutrient-based signals through metabolism of ingested nutrients. Although the relevance of these more physiological elements of satiety have been well reviewed (2-4), the extent to which more cognitive and sensory components influence satiety is less well understood, and is focussed on in this brief review.

EFFECTIVE MEASUREMENT OF SATIATION AND SATIETY

The demonstration of enhanced satiety, or more rapid satiation, through consumption of a novel food, drink or other product, requires measurement of relevant aspects of behaviour both following the putative satiety agent and appropriate controls. No single measure of behaviour is likely to capture effectively either satiation or satiety, and readers wanting more detailed information may find these reviews helpful (5, 6).

The most commonly used measure through which satiation and satiety can be inferred is quantification of intake either of the product itself as a measure of satiation, or at subsequent eating events as an index of satiety. However, the size of an eating event can be modified by multiple factors, most notably by the palatability (immediate sensory appeal) of the item being ingested. Likewise, many manipulations, including those generated by side-effects such as induced nausea etc., may modify subsequent intake, but cannot be interpreted as enhanced satiety. Thus evidence of specific actions on satiation and/or satiety requires additional measures that can discriminate between different causes of changes in intake. Thus, most studies of satiation and satiety combine intake with measures either relating to experiential aspects of satiety, such as various ratings of appetite, or more direct behavioural measures of ingestion such as eating rate and cumulative food intake within an eating episode.

The value of multiple measures in assessing causes of differences in intake is illustrated in Figure 2. Here two manipulations modified intake to a similar extent. The first manipulation (Figure 2a) altered the sensory appeal of the food by modifying salt content, while the second had the...
same food consumed after either a low or high energy soup preload (Figure 2b: [7]). Analysis of the changes in appetite ratings within these meals allowed a discrimination of mechanism. In the first instance (Figure 2c) rated hunger was the same at the onset of eating but increased during the early phase of the meal with the more liked food (the “appetizer effect”: [8]). In contrast, prior consumption of a high energy soup 30 minutes before the meal resulted in an initial decrease in hunger (Figure 2d), and this can be interpreted as evidence of enhanced satiety, but the similar changes in appetite within the meal suggests satiation was unaltered.

To achieve this level of behavioural sophistication, intake has to be measured more accurately than simple weighing of overall intake. Kissileff [9] developed the original Universal Eating Monitor (UEM) to achieve this, with intake measured using a hidden balance. Linking the UEM to a computer, and using changes in weight to trigger on-screen ratings of appetite, has allowed development of a sophisticated tool to assess satiety, the Sussex Ingestion Pattern Monitor (for more details please see www.sipm.co.uk). The pattern of changes in intake within a meal also give an index of satiation, with the normal response being a decline in eating rate as the meal progresses (10, 11). The observation that people who are prone to over-eating such as the obese and sufferers from binge-eating disorder show disruptions from the normal pattern of satiation has been instrumental in identifying the nature of these eating-related problems [12, 13].

In addition to behavioural measures of satiety, post-ingestive physiological satiety cues such as measurements of gastric fill, and release of putative satiety hormones such as polypeptide YY (PYY), cholecystokinin (CCK) and (GLP1), and levels of the “hunger hormone” ghrelin, can also be integrated into the study of satiety, and serve as useful biomarkers of satiety responses [2, 14]. However, such measures can only be interpreted in association with behavioural measures of satiety since the correspondence between these biomarkers and behaviour can be poor. For example, obese patients over-consume despite having lower levels of circulating ghrelin than do normal-weight controls [15].

Overall, effective measurement of satiation and satiety requires multiple behavioural measures, and most studies consequently combine measurements of rated appetite alongside intake measures.

**PSYCHOLOGICAL COMPONENTS OF SATIATION AND SATIETY**

Many people believe that a typical meal ends because of feelings of fullness generated by gastric signals arising from accumulation of food in the stomach. However, an alternative view is that meal size is determined by a combination of habit and memory for the quantity of food perceived to have passed through the mouth along with expectations about how full the consumer will subsequently feel. Several lines of evidence suggest that cognitive factors are the main controllers of normal meal size. One study that strongly suggested this involved participants eating a simple lunch (pasta in tomato sauce) while having a second liquid food (tomato soup) infused directly into their stomachs via a naso-gastric tube [16]. The striking finding (Figure 3) was that infusion of 150ml of low energy soup or 450ml of soup with treble the energy density resulted in only a small decrease in voluntary intake of pasta [575g after the 150ml low infusion, 525g after the 450ml high infusion], even though the total energy ingested (adding together what was eaten and infused) more than doubled (from 143kJ to 293kJ). Thus neither energy nor volume signals had a significant impact on the point at which the meal was terminated in this study. These data concur with studies suggesting that gastric pressure alone has little role in controlling meal-size for normal meals: for example, artificial distension of the stomach immediately before a meal had minimal effects on how much was consumed [17].

The importance of visual cues in satiation was demonstrated in an ingenious experiment where people consumed soup from a bowl that was refilled automatically at a rate that the consumer was unaware of [18]. Meal size increased markedly when the bowl was surreptitiously topped up while eating, but ended early when the bowl was partially drained while participants ate. In both cases the same degree of satiety was achieved; people felt as full having consumed a small portion (157kcal) as when they had consumed a large portion (268kcal). Thus both these studies show that habit and orosensory experience are prime determinants of meal size, with minimal influence of post-ingestive cues. Indeed, it can be argued that meal size is more a consequence of how much food we select rather than how much of the selected food we then go on to consume [19], perhaps enhanced by early encouragement to “empty our plates”.

What then is the evidence that cognitive influences impact satiety as well as satiation? Recent evidence clearly suggests that memory for recent eating events is important; having attention drawn to what was consumed at the most recent eating event caused a reliable reduction in intake without altering changes in the experience of satiety [20]. In that study, participants consumed a simple snack food (popcorn) mid-afternoon either having been asked to recall what they
had eaten for lunch, or what they had eaten for lunch the previous day. Recalling the more recent lunch reduced intake but satiety (indexed by fullness ratings) was similar, implying the memory of recent eating magnified the satiating effects of the snack. Together these findings suggest that what consumers experience in terms of their visual appreciation and knowledge of what they have consumed can over-ride actual effects of nutrients.

Knowing that beliefs and expectations can influence satiety in this way, an important question for product developers is how to influence these psychological aspects of satiation and satiety. One possibility is to modify the sensory quality of the product to generate a satiety-relevant expectation. For example, we recently found that a whey-protein enriched beverage was more satiating when presented in the context of satiety-congruent sensory features (higher viscosity, more creamy flavour) than either the protein or sensory qualities on their own. Thus expectations may prime the system to anticipate the satiating effects of nutrients and so lead to more effective satiety development. It may be that effective expectations could then be generated through cues in product labelling.

**LEARNING, SATIETY AND ACCEPTABILITY**

When a product is first consumed, the consumer is likely to have some expectation of how filling the product will be based on information from packaging and sensory quality. Once the product has been consumed, actual physiological effects of ingestion will lead to a cascade of satiety-related signals. These signals may then become associated with the product in a number of different ways, and lead to consequent changes in product liking and satiety expectations. Thus repeated consumption should lead to predictable changes in product acceptability through learning, and developers should be able to use information about the likely effects of learning to ensure that products become more liked over time.

The two critical psychological processes involved in effects of repeat exposure in this context are flavour-nutrient learning and learned satiety. Flavour-nutrient learning refers to the formation of associations between the flavour of the ingested product and the consequent post-ingestive experience. If ingestion leads to an unpleasant consequence, a flavour-aversion may develop and the product is likely to be rejected, but an enjoyable post-ingestive consequence such as an acceptable level of satiety, increased energy, etc., may all lead to increased product acceptability. For example, liking for a novel sorbet increased when the sorbet flavour was associated with a sweet taste and ingestion of energy [21]. In contrast, the idea of learned satiety is that increased familiarity with the degree to which a product is satiating allows acquired control of the size of subsequent meals [22]. However, appealing though this idea is, the most recent evidence suggests that this only occurs when ingestion leads to an unpleasant state of over-satiation, and is directed by changes in liking [23].

Repeat consumption of a product is likely to lead to greater familiarity with its satiating effects, and consequently alter liking. This idea fits with the observation that liking and energy density are closely linked [24], and that liking remains a prime driver of food choice [25]. It is likely, but as yet unproven, that the learning processes that associate flavour with consequence may modify expectations about a product which in turn alter how and when the product is consumed. Future research needs to target this relationship if we are to gain real insights into how these processes govern consumer behaviour. Ultimately, an understanding of how product formulation may modify the learning processes associated with liking change and interact with expectations are likely to be key in developing products which are satiating but which consumers will want to use repeatedly.

**IMPLICATIONS FOR FUTURE PRODUCT DEVELOPMENT**

A better understanding of the way in which consumer expectations integrate with sensory quality and nutrient formulation of products will in the future allow both targeted development of products in specific sectors, such as weight management, and more generally in the production of more general foods and drinks which counter the tendency to over-consume that underlies the current obesity crisis. This is likely to require a shift in the approach to product design from one where initial product development is followed by optimization of sensory quality and then marketing to an approach where these three strands are integrated at an early stage. For example, promotion of foods as reduced energy may prove to be counter-productive as they may generate weak satiety expectations and so lead to less effective responses to actual nutrient content. Better understanding of the learning processes through which liking for products may change over time may also help improve repeated purchase patterns for foods developed to provide optimised satiety [26]. We are still some way from being able to define the design rules needed to promote rapid satiation and prolonged satiety in a product, but recent advances and ongoing research suggest this will be achievable within the next few years.
SUMMARY

Recent advances in understanding of psychological influences on satiation and satiety pose important challenges for formulation of future satiating products. The recognition that satiety is not simply a consequence of the physiological consequences of ingested nutrients, but instead represents an integration of nutrient, sensory and cognitive components, suggests that all three elements need to be considered when trying to develop products that might enhance weight control. Once consumers try such products, a variety of learning mechanisms will further adjust these relationships, and thereby modify flavor liking and consequent product acceptability. As we come closer to understanding these inter-relationships, so new opportunities will arise to allow more effective product development and marketing.

REFERENCES AND NOTES