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The effect of sensory–nutrient congruency on food intake after repeated exposure: Do texture and/or energy density matter?☆,☆☆

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HIGHLIGHTS

- Sensory cues help to predict a food's satiating effect, and guide food intake.
- Changes in thickness and creaminess of foods alter satiety and subsequent intake.
- It is unclear whether effects of sensory manipulations change over repeated exposure.
- Repeated exposure modified intake following incongruent sensory-nutrient pairings.
- Following repeated exposure, intake depended on the energy density of the preloads.

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ABSTRACT

Sensory properties guide the amount that people eat. In particular, food texture plays an important role in a food's 'expected satiation', which in turn affects the food-related decision making process. One hypothesis is that incongruent pairing of a textural cue with a post-ingestive outcome compromises this process, leading to poor energy compensation. Several studies examined the effect of both energy density and sensory characteristics (i.e. increased creaminess and thickness) on expectations, subjective appetite and food intake. To add to this literature, a re-analysis of data assessed whether the effect of sensory–nutrient pairings on energy intake compensation persisted after repeated exposure to a food. In this cross-over design, 27 participants consumed two preloads with 'congruent' (low-energy/liquid; high-energy/semi-solid) and two preloads with 'incongruent' (low-energy/semi-solid; high-energy/liquid) texture–nutrient combinations for nine subsequent meals, during which ad libitum intake was measured. Intake at first exposure did not differ between the low-energy (280 ± 150 kcal) and high-energy preloads (292 ± 183 kcal) in the incongruent conditions. By contrast, it was greater after the low-energy (332 ± 203 kcal) than after the high-energy (236 ± 132 kcal) preload in the congruent conditions (energy $*$ incongruent/congruent, $p = 0.04$). Post-exposure, this pattern changed: intake depended on the energy density of the preloads in all conditions, and was greater after low-energy preloads (day $*$ energy $*$ incongruent/congruent-interaction for breakfast: $p = 0.02$). Thus, manipulating the sensory properties of a food influenced energy compensation and meal size, but only at initial exposure. Repeated exposure 'corrected' the initial lack of compensation observed in conditions with incongruent sensory–nutrient pairings.

1. Introduction: sensory–nutrient learning

The amount of food that we consume is based largely on previous experience [1]. We learn to estimate and anticipate a food's satiating capacity, and the sensory properties of a food (such as taste, smell, or texture) serve as a cue to guide portion selection [2]. However, studies on this 'flavor–nutrient satiety learning' have shown inconsistent results in adjustments in energy intake (e.g. [3–5] vs. [6–8]). This can be partly explained by the observation that laboratory experiments can be affected by subtle, but important variations in the experimental design [9], for example inclusion of novel vs. familiar foods; adequate differences in the energy density of the foods; and characteristics of the participants; e.g. in terms of restraint [9].

In addition to these design features, it could be that sensory cues other than flavor per se could be more effective in sensory–nutrient learning. In a series of studies to better understand the nature of flavor–nutrient learning [10–13], it was questioned whether differences in food texture, or more specifically viscosity/thickness, could explain some of the variety in the outcomes of flavor–nutrient learning studies. A short sensory

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exposure time to liquid foods could be insufficient to enable subjects to associate the sensory attributes of the foods with their satiating effects, whereas a longer oro-sensory exposure when consuming e.g. semi-solid foods would potentially facilitate learning [14,15]. It was observed that participants adjusted appetite sensations and/or intake in response to repeated consumption of dairy products of which viscosity and energy densities were manipulated [10,12,13], but these changes were made irrespective of the viscosity of the test foods[12,13]. Thus, these results did not show evidence for a modulating role of this aspect of food texture in energy learning. However, the findings indicated a clear effect of viscosity on satiation: ad libitum intake of liquid foods was up to 30% higher when compared with semi-solid foods.

Differences between satiation of liquid and semi-solid foods may be explained not only by differences in oro-sensory exposure, but also by differences in expectations regarding the satiating capacity generated by these foods. These expectations may play an important role in the decision on the amount of food to be consumed (e.g. [16–19]). It has been observed that beverages evoked lower expected satiation values [20], and that 'expected satiation' of dairy products increased consistently with thickness [21]. Thus, the viscosity of a food may serve as a clear cue to guide decisions on portion size and energy intake. With this in mind, texture cues may have the potential to alter satiety responses, by e.g. increasing satiety responses to thicker foods [22]. These alterations of the satiety responses could result in imprecise caloric compensation, i.e. a failure to moderate energy intake at a subsequent meal. This could have either a favorable (lower caloric intake after e.g. thicker foods that increased satiety responses) or an unfavorable effect on energy intake (overeating after e.g. liquid foods that evoked weak satiety responses). Studies that report caloric intake after repeated consumption of foods with altered texture (viscosity)–nutrient pairings are limited, but could indicate whether unfavorable effects of incongruent pairings (i.e. overeating) would emerge, and whether these effects persist or change over repeated consumption. With the process of flavor–nutrient learning in mind, it was hypothesized that repeated consumption alters the effect of sensory–nutrient incongruence: upon first exposure to a food, caloric compensation is expected to be imprecise — increasing the risk for overconsumption. Through learning about the energy content of the food during repeated consumption, caloric compensation will be improved, with favorable effects for energy intake (i.e. reduction of overconsumption). To test this hypothesis, a re-analysis of previously collected data [13] was added to a short overview on studies that investigated the effect of sensory–nutrient incongruence on food intake.

1.1. The effect of viscosity on satiety and food intake

Humans use the sensory attributes (e.g., viscosity or sweetness) of food to predict its post-ingestive effects and to moderate meal size accordingly. Solid foods or thicker products are expected to have higher satiation values than liquid foods [20,21]. With this in mind, sensory manipulations could potentially be used to weaken or to enhance the satiating effect of foods [22]. To investigate the latter, participants were served LE and HE preloads with three different sensory contexts, by changing the thickness and creaminess of the drink [22]. Food intake was measured during a two-course ad libitum meal 30 min later. Total food intake following the LE preloads did not seem to change across the foods with different thickness and creaminess, but stronger satiety and more accurate compensation was generated when covert increase of energy was presented with satiety-congruent sensory characteristics (i.e. HE preloads being thicker and creamier). Thus, small increases in viscosity that predicted the energy load of the HE food changed the satiety responses [22].

It was then investigated whether differences in decisions about consumption could be explained by differences in satiety expectations of the beverages with different thickness and creaminess [23]. Results showed that thick drinks were expected to be more filling than thin drinks, and creamy drinks were rated as more filling than low-creamy versions — independent of the energy content. This replication of the previous results [22] was observed only for the female participants, viscosity of the preloads did not affect intake of males. Also, stronger satiety effects were observed following consumption of a high-protein preload that was thicker and creamier than a high-protein preload without these sensory characteristics [24]. An iso-caloric high-carbohydrate preload that was as thick and creamy as the high protein preload generated similar satiety effects.

These studies showed that thicker and creamier versions of a food enhance the satiety responses to the food after a single exposure. Expectations and intake may reflect learning throughout life-time: with a single exposure to a food there has not been an opportunity to learn about the satiation capacity of a food, and behavior may be based on previous experiences with thicker and creamier foods. Through learning about the energy content of the food during repeated consumption, it is expected that caloric compensation will improve.

1.2. The effect of viscosity on intake after repeated exposure

The results described above suggest that sensory attributes of a food (beverage) are important for the development of satiety. Previous experience with creamy and/or thick foods and post-ingestive effects following consumption may have resulted in the belief that foods with these sensory characteristics are more filling, therewith increasing the acute satiating effects of the ingested nutrients [22–25]. An interesting question is whether these effects of sensory manipulations persist after repeated exposure.

To answer this question, Yeomans et al. [26] repeatedly served one of four versions of a beverage as a mid-morning snack: a drink with either a low or high energy density and either low or high thickness and creaminess. Before (day 1) and after (day 6) repeated consumption, subjects were served an ad libitum meal 90 min after the preload, and intake was measured. A three-way interaction between time (test day), energy and sensory attributes indicated changes in intake over repeated consumption. At first exposure, test meal intake, as well as total intake (preload + test meal), depended on both sensory characteristics and energy density: participants consumed a smaller amount following the HE preload with enhanced creaminess and thickness. After repeated exposure, test meal intake depended on energy density, with greater intake following LE preloads as compared to HE preloads, independent of the thickness or creaminess of the preloads. The most prominent change over repeated exposure was an increase in intake following the LE preloads.

Interestingly, a similar increase in ad libitum intake following repeated exposure to LE preloads was observed in a previous study, which aimed to assess the role of food texture in energy learning [13]. In this cross-over study with four conditions, data were collected for 27 subjects who repeatedly consumed novel foods based on gelatin and starch that were either LE or HE, and either liquid or semi-solid. Results showed that test meal intake following repeated consumption depended on energy density of the test foods; adjustments in intake were made independent of viscosity of the foods [13]. It will however be interesting to see if sensory manipulations that break the 'predictive' relationships (i.e., semi-solid texture predicts a higher satiating capacity [21,22]) affect food intake in a similar manner as described in the studies above, i.e. after both single and repeated exposure. Thus, data of this learning experiment [13] were re-analyzed to investigate the effect of sensory–nutrient incongruence on food intake after repeated exposure.

1.3. The effect of incongruent sensory–nutrient characteristics on intake after repeated exposure: a re-analysis

1.3.1. Methods

This randomized cross-over study, including its participant recruitment, test food composition, and experimental design, has been