ROOM FOR DESSERT!

A series of studies on sensory satiation and food variety

Anouk Hendriks-Hartensveld

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General introduction

Forty years ago, two papers were published in the scientific journal Physiology & Behavior, describing a number of experiments on ingestive behaviour conducted by Barbara Rolls and her colleagues. These two papers are considered classic studies in ingestive behaviour and (together) have been cited over 1500 times. In one of the two papers, two experiments investigating a phenomenon called sensory-specific satiety are discussed (B. J. Rolls, E. T. Rolls, et al., 1981). The other paper comprises three experiments reporting a related phenomenon: the so-called 'variety effect' (B. J. Rolls, Rowe, et al., 1981). Both sensory-specific satiety and the variety effect are the topic of this dissertation.

In Experiment 1 of the 'sensory-specific satiety' paper, Barbara Rolls and her colleagues (1981) asked their study participants to taste and evaluate the pleasantness of eight foods, to consume one of these foods (the 'test' food) ad libitum (freely) until they felt satiated, and then to again evaluate the pleasantness of the same eight foods two and twenty minutes after finishing the ad libitum meal. In Experiment 2, participants were asked to: (i) taste and evaluate how much they liked and how much they wanted to eat eight foods; (ii) consume one of the foods ad libitum to satiety; (iii) taste and evaluate the same eight foods for a second time. But this time, after the second round of tasting, the participants were offered an unexpected second course to eat ad libitum. This second surprise course was either the same test food as they just ate until feeling satiated, or a different food. In both experiments, rated pleasantness of the test food markedly declined relative to the other uneaten foods. This hedonic decline persisted for 20 minutes after the ad libitum consumption (Experiment 1). Furthermore, in the second experiment, participants who received a different food in the surprise second course ate significantly more than did participants who received the same test food again. This is important as it demonstrates that sensory-specific satiety is a subjective phenomenon with clear behavioural implications. If sensory-specific satiety would not have had any effect on food intake, the whole phenomenon could have been qualified as interesting but essentially irrelevant. Moreover, the latter finding suggests a 'variety effect', the main focus of the other classic study by Barbara Rolls and colleagues published in 1981.

In their paper entitled 'Variety in a meal enhances food intake in man', Rolls and colleagues (B. J. Rolls, Rowe, et al., 1981) present three experiments investigating whether participants eat more if they are offered a variety of foods as opposed to only one food. In the first experiment, either sandwiches with four different fillings were offered (each as a successive course) or four courses of the same sandwich, from which the participants could eat ad libitum. In the second experiment, participants again received successive courses to eat freely from, but instead of sandwiches, three different flavours of yogurt were served (which were of equal energy density but had a different flavour, appearance, and texture). In the third experiment, again three successive courses of yogurt were offered to participants, but this time, the three yogurts presented in the 'variety meal' only differed in flavour (and were similar in appearance and texture). In the first and second experiment, more was eaten when a variety of foods was presented, as opposed to just one type. Food intake was even greater in the variety meal when compared to the plain meal with the most preferred yogurt (Experiment 2). However, in Experiment 3, when the yogurts presented in the variety meal only differed in flavour, no significant increase in consumption was observed. B. J. Rolls, Rowe, et al. (1981) thus concluded that: "… the more dissimilar the foods are, the more likely it is that the effect will appear" (p. 220). In other words, this 'variety effect' (i.e., increased appetite with increased meal variety) only occurs when foods are markedly distinct.

The two papers discussed above provided strong evidence that there is a satiation that is sensory-specific; the sensory pleasure derived from a food changes with consumption. This 'satiation' is specific to the sensory qualities of that food, and does not depend on post-ingestive feedback (Hetherington & Havermans, 2013). It was hypothesized to be the mechanism accounting for the consumption encouraging effect of food variety (i.e., the variety effect): when pleasantness derived from a food has declined so much that its consumption is terminated, eating will be resumed when a different (sufficiently liked) food is available. In other words, sensory-specific satiety and the variety effect are two sides of the same coin, with sensory-specific satiety promoting variety seeking and the offer of food variety limiting sensory-specific satiety.

The current dissertation includes a series of experiments on sensory-specific satiety and food variety, two phenomena that strongly affect what and how much is eaten. Sensory-specific satiety is actually more accurately described as sensory-specific satiation, because it influences satiation (a process contributing to meal termination) and not so much satiety (processes contributing to the motivation to eat in between meals). Therefore, in this dissertation, the term sensory-specific satiation will be used, which is abbreviated to SSS as from this point. In this introduction, some further background will be provided regarding SSS and the variety effect. Firstly, early evidence of SSS and the variety effect in animal and human research will be summarized; secondly, central characteristics and definitions will be outlined; thirdly, research into potential moderators will be discussed; and fourthly, the content of this dissertation is presented.

Early evidence of SSS and the variety effect in animal and human research

The old Dutch saying 'verandering van spijs doet eten' (a change of food makes one eat) suggests that people have always been aware of the variety effect (and possibly SSS). So, Barbara Rolls and colleagues did not discover SSS and the variety effect. And contrary to what some scholars state (see e.g., Embling et al., 2021), Rolls and colleagues weren't the first to find empirical evidence for these phenomena. Observations of SSS and the variety effect had been reported in animals and in humans well before 1981. The first published observation of SSS and the variety effect in animals can be traced back to 1935, when David Katz noted that hens eat more grain when they are fed more than one type of grain compared to only one type. He postulated that hunger and appetite can be distinguished, with appetite being modifiable: "…when only one kind of food is offered, satiety very soon occurs, but this can be retarded by mixing with the food one or two other kinds" (Katz, 1935, p. 322). More evidence of SSS and the variety effect was found in rats (Young, 1940; Le Magnen, 1956[1999]; Jones, 1970; Hsiao & Tuntland, 1971; Morrison, 1974; B. J. Rolls, 1979), and in cats (see Mugford, 1977).

Evidence for the variety effect in humans was first mentioned in an unpublished PhD thesis by Shaw (1973). Asking participants to consume a fixed amount of a 'preload' meal and, after that, letting them eat freely from a meal that was either the same or a different meal, Shaw found that the participants who had the different meal ate significantly more than the participants who received the same meal again (Pliner et al., 1980). Bellisle and Le Magnen (1980) also demonstrated the variety effect in humans, and Pliner and colleagues discussed a 'sensory-specific oral satiety' as well as evidence of a 'variety effect' in a 1980 paper describing two studies investigating an 'oral satiety mechanism'. In the first study, they presented men with obesity, men with normal weight who were dieting (restrained eaters), and men with normal weight who were not dieting (non-restrained eaters) with a varied or a single food meal. Independent of weight status or dieting behaviour, the men consumed more of the varied meal (demonstrating a variety effect). In the second study, Pliner and colleagues showed that pleasantness of a food decreased with its consumption (indicative of SSS).

Characterizing SSS

Although various studies (discussed in the sections above) already provided some evidence for SSS and the variety effect, the work by Barbara Rolls and her colleagues was the starting point for the truly systematic investigation of SSS and the variety effect. It prompted various research groups to examine the roles that SSS and the variety effect might play in food consumption and food choice, and what factors could affect them. In the past four decades, several book chapters (Hetherington & Rolls, 1996; Hetherington & Havermans, 2013; Vickers, 2017), reviews (B. J. Rolls, 1986; Raynor & Epstein, 2001; Remick et al., 2009; McCrory et al., 2012; Raynor & Vadiveloo, 2018), and a (recent) meta-analysis (Embling et al., 2021) have been dedicated to discussing the evidence, characteristics, proposed mechanisms, and influences on SSS and the variety effect. The meta-analysis conducted by Embling and her colleagues weighed the evidence so far for the variety effect. A small to medium effect of variety on intake was found, prompting Embling et al. (p. 1) to conclude: "…variety is a robust driver of food intake". A meta-analysis of SSS is still lacking, but there is widespread consensus that SSS is a robust determinant of meal termination (Hetherington & Havermans, 2013; Hetherington & Rolls, 1996).

As mentioned, many researchers have explored the nature of SSS, resulting in a growing understanding of its basic tenets. Some central characteristics of SSS have been identified, which are summarized in Box 1. Importantly, SSS refers to a hedonic decline for a food that is immediate with its consumption and is food specific, which implies that it does not require any post-ingestive feedback. This immediacy and food specificity differentiate it from (negative) alliesthesia (Cabanac, 1971), which does depend on post-ingestive processes. According to the alliesthesia account, ingestion of a specific food causes the pleasantness of a (physiologically) similar food to decline due to changes in the internal state following ingestion (the physiological need of the body is met) (Cabanac, 1979).

Box 1. Characteristics of SSS.

- The general definition of SSS is “the changing hedonic response to the sensory properties of a particular food as it is consumed” (B. J. Rolls, 1986, p. 95).
- These ‘sensory properties’ can be flavour, odour, shape/texture, or (possibly) colour (Vickers, 2017; Raynor & Epstein, 2001; Piqueras-Fiszman & Spence, 2014).
- SSS is specific to the food that is consumed. Other foods remain equally pleasant (Hetherington & Havermans, 2013).
- SSS is not dependent on post-ingestive physiological signals. It occurs before post-ingestive processes have commenced (Hetherington & Rolls, 1996).
- SSS can be maintained up to 2 hours after eating (Hetherington & Havermans, 2013; Raynor & Epstein, 2001; Weenen et al., 2005; Rogers et al., 2020).
- SSS affects food consumption: rejection of the same or similar foods, and acceptance of other foods (Hetherington & Havermans, 2013).
- SSS is determined by the amount of orosensory exposure to the food; sham-feeding a food (only chewing but not swallowing) or only smelling a food induces SSS (Hetherington & Havermans, 2013; E. T. Rolls & J. H. Rolls, 1997; Smeets & Westerterp-Plantenga, 2006; Nolan & Hetherington, 2009; but see Romer et al., 2006; Ramaekers et al., 2014; Zoon et al., 2016).

1

The standard paradigm to test SSS was devised by Barbara Rolls and colleagues (B. J. Rolls, E. T. Rolls, et al., 1981) and is visually summarized in Figures 1 and 2 (see also Vickers, 2017). In the standard SSS test protocol, participants are asked to taste and indicate their liking of a range of foods (A-H in Figures 1 and 2). Next, participants consume a food ad libitum or aliquots of a fixed food serving (F in Figures 1 and 2), after which they repeat the ratings of foods A-H. The change in liking (i.e., the pleasantness derived from consumption) of the consumed food (F) is then compared with the mean change in liking of the unconsumed foods (A, B, C, D, E, G, H). SSS is established when the liking rating of the consumed food drops significantly more than the mean liking of the unconsumed foods.

Figure 1. The SSS test paradigm consists of three phases. First, an SSS pre-test takes place in which a number of foods are tasted and evaluated (left box). Second, one of the tasted foods is consumed either ad libitum or as a fixed portion (middle box). Third, the SSS test (tasting and evaluating foods) is repeated (SSS post-test; right box).

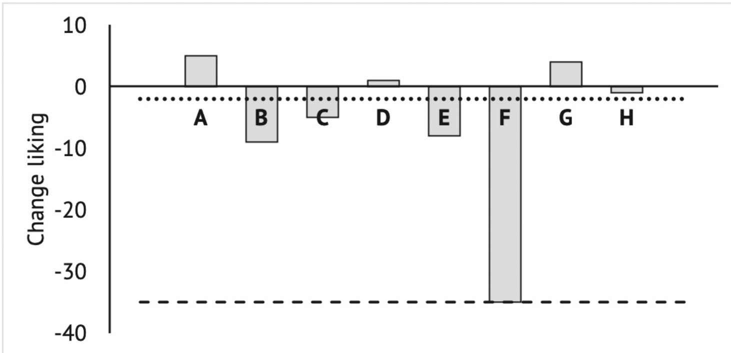

Figure 2. To test SSS, the mean change in liking of the uneaten foods (A, B, C, D, E, G, H – dotted line) is compared with the change in liking for the consumed food (F – dashed line). Liking is usually measured in mm on a 100 mm line scale ranging from 0-100.

SSS clearly plays an important role in satiation and due to its rapid onset (during consumption) and primary dependence on the sensory properties of food, its effects are likely to play a role in early satiety as well. Its place in the development of satiation and satiety can be visualized with the satiety cascade as proposed by Blundell et al. (1987) (see Figure 3 below). In the satiety cascade, 'satiation' and 'satiety' are separated in the time course of consumption; the former term referring to the process leading to the termination of an eating bout, and the latter term referring to the staving off of hunger after this eating bout (i.e., inhibiting eating for a while). Sensory and cognitive factors have been proposed to mainly play a role in satiation and early satiety, whereas post-ingestive and post-absorptive factors (i.e., the hormonal and metabolic consequences of food ingestion) play a role later in the time course of satiety (Bellisle & Blundell, 2013).

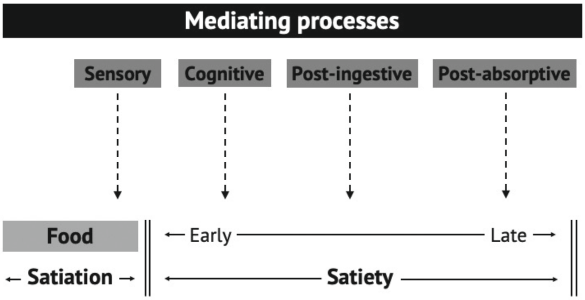

Figure 3. The satiety cascade as drawn up by Blundell et al. (1987), with SSS mainly contributing to satiation.

Characterizing the variety effect

Contrary to the clear definition of SSS, the variety effect has been defined and operationalized in different ways across studies. For example, food variety has been measured both within a meal (e.g., Meengs et al., 2012) and between meals (e.g., Meiselman et al., 2000) (see also Remick et al., 2009). See Figure 4 for an example of within-meal variety. Also, in the experiments investigating the variety effect in single meals, the foods within the varied meals were presented either serially (e.g., B. J. Rolls, Rowe, et al., 1981), or all at once (e.g., Pliner et al., 1980). Furthermore, variety has been defined as a meal composed of distinct items or dishes (food-based approach; see e.g., Pliner et al., 1980), as a single dish containing multiple components such as a casserole or a soup (ingredient-based approach; see e.g., Johnson & Vickers, 1992), or as a single food (group) that comes in different varieties (sensorial-based; e.g., green vs. red bell peppers; Vadiveloo et al., 2019) (Raynor & Vadiveloo, 2018). In Embling's et al. (2021) meta-analysis, different operationalizations of 'variety' were not found to influence the magnitude of the variety effect. Embling and colleagues further did not find any effects of the types of test foods used in the experiments (fruits and vegetables versus other food groups) or the number of sensory characteristics that were 'varied' as was originally suggested by Barbara Rolls (see B. J. Rolls, Rowe, et al., 1981).

It is important to note that, since SSS occurs within a meal and recovers some time after that meal, across-meal variety or dietary variety (variety over weeks or months) effects may not be the result of SSS. Instead, these variations of food variety may more likely be related to monotony (or 'long-term acceptability'): a decrease in liking for a food due to food repetition across meals (for a discussion of monotony and 'across-meal' or 'dietary' variety see Remick et al., 2009; or Raynor & Epstein, 2001). Monotony superficially may appear to simply reflect long-term SSS, but there are reasons to believe that monotony and SSS are separate phenomena. This will be discussed further in the discussion section of this dissertation. Importantly, the studies in this dissertation centre on SSS and as such only consider the within-meal variety effect.

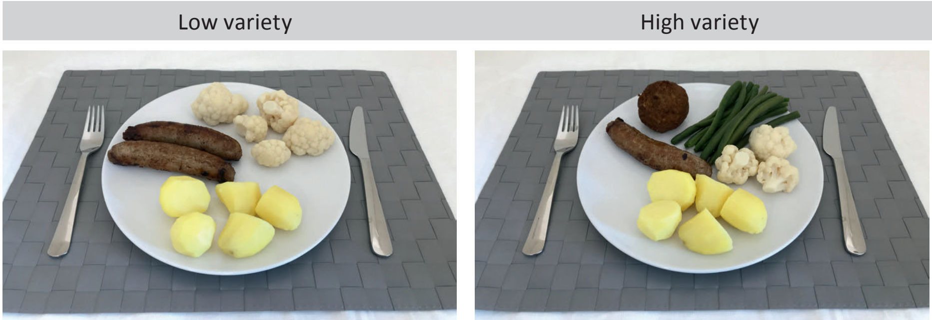

Figure 4. Example of low and high within-meal variety in a traditional Dutch dinner meal.

Potential moderators of SSS and the variety effect

A large array of factors that have been hypothesized to affect SSS and the variety effect have been explored. As these factors can influence the termination or enlargement of a meal, they are highly relevant to study. They can be categorized into: food characteristics, individual characteristics, and characteristics of the meal situation. Evidence of the influences of these characteristics will be discussed in the subsequent sections.

Characteristics of the food/meal

Food properties that have been examined as possible moderators of SSS and the variety effect can be categorized into nutritional properties (energy density, volume, and macronutrient composition) and sensory properties (texture, intensity, complexity, and palatability). Much of the research on SSS and the variety effect has focused on the moderating role of nutritional properties (see e.g., Bell et al., 2003; Remick et al., 2009). Many studies have examined the role of energy density and show that it does not influence SSS (and the variety effect) (Remick et al., 2009; Raynor & Epstein, 2001). Less consistent evidence has been found regarding volume and weight of the food. However, most of the studies find that volume and weight affect SSS: a greater volume of food typically produces more SSS (Remick et al., 2009).

Studies investigating the influence of macronutrient content on SSS and the variety effect have examined whether SSS is specific to the macronutrient content or the sensory properties of a food. In other words, when one has eaten a food mainly consisting of carbohydrates, will SSS transfer to a different food that also contains (mainly) carbohydrates? The findings of these studies clearly show that SSS depends on sensory input, not the macronutrient content of a food (Raynor & Epstein, 2001; Remick et al., 2009). Additionally, studies concerning macronutrient content have investigated whether protein, carbohydrate and fat produce a different degree of SSS (e.g., does eating a high-fat food result in more SSS than eating a food high in carbohydrate?). Due to methodological difficulties to investigate this question (e.g., due to confounding of energy density and macronutrient content and the difficulty to define what constitutes a food 'high' in one of these macronutrients) results of these studies should be interpreted with caution. Overall, no clear differences in magnitude of SSS for protein, carbohydrate or fat have been found (Remick et al., 2009). Only weak evidence was found that protein might produce slightly more SSS than carbohydrate and fat (Remick et al., 2009; Vickers, 2017; see also Meillon et al., 2013).

Studies investigating the effect of sensory properties (texture, intensity, complexity, and palatability) on SSS and the variety effect have shown that some sensory properties can affect SSS, while others do not. Some evidence has been found that texture can affect SSS (Hetherington & Havermans, 2013; Maier et al., 2007). Bolhuis and Forde (2020) and De Graaf (2012) argue that texture affects food intake by influencing eating rate. For example, a dry and tough piece of food requires a lot of chewing before the bolus can be swallowed. This texture ensures a relatively extensive orosensory exposure to this type of food, promoting the development of SSS. Conversely, liquids allow for rapid intake, limiting SSS and hence facilitating energy intake.

Conflicting evidence has been found regarding the effect of flavour intensity on SSS. Maier et al. (2007) found more intense foods to produce more SSS (see also Vickers & Holton, 1998), but Havermans et al. (2009) found no effect of intensity on SSS in two experiments, and Chung and Vickers (2007) found that lower sweetness could even produce stronger SSS.

Sensory complexity has also been studied in relation to SSS. Summarizing these results is complicated due to the fact that sensory complexity has also been denoted as 'sensory variety' (see e.g., Johnson & Vickers, 1992), but overall, complexity does not seem to affect SSS (Vickers, 2017; Remick et al., 2009; Weijzen et al., 2008). Lastly, palatability has not been found to affect SSS (Remick et al., 2009). The relative drop in liking of more and less liked foods does not differ from each other.

In sum, the only food properties that seem to affect SSS and/or the variety effect are volume, weight, and texture. Energy density, macronutrient content, complexity, and palatability do not seem to affect SSS and/or the variety effect. Results are mixed with regard to the effect of flavour intensity on SSS, but if there is any effect of intensity at all, it is likely to be small.

Characteristics of the individual

In their meta-analysis of the variety effect, Embling et al. (2021) found that characteristics of the individual such as gender and weight status (underweight, normal weight, and overweight) do not influence the variety effect. Remick et al. (2009) report evidence in their review of SSS and the variety effect that nutrient knowledge of the consumed foods does not seem to affect SSS, and that gender, weight, and dietary restraint do not moderate either SSS or the variety effect (e.g., Brondel et al., 2007; Havermans et al., 2012).

Age may be a notable exception to the findings that individual characteristics play no role in SSS and the variety effect. Two studies have shown that the susceptibility to

SSS seems diminished in elderly (Rolls & McDermott, 1991; Hollis & Henry, 2007). This is remarkable as it does seem that all age groups are equally susceptible to the variety effect (Embling et al., 2021; Remick et al., 2009). In other words, the variety effect is perhaps not fully explained by SSS (see also Remick et al., 2009).

Characteristics of the meal situation

Characteristics of the meal situation that have been studied in relation to SSS and the variety effect pertain to the perception of the situation (the attentional focus during consumption, perceived availability, and perceived variety of the foods) or the actual eating context. Some evidence of an effect of attentional focus on SSS has been found (Remick et al., 2009; Braude & Stevenson, 2014; Rogers et al., 2021). For example, Braude and Stevenson (2014) found that watching television while eating affects SSS. They let female students consume snack foods ad libitum on two occasions: once while watching television and once without any distractions. One group of students consumed only one snack food, while another group could eat from four different snack foods. Both groups ate more when they were watching television, and SSS was absent when the students who ate one snack food were watching television while eating.

No evidence has been found for an effect of perceived food availability and variety on SSS (Havermans & Brondel, 2012; Wilkinson & Brunstrom, 2016). Note however, that merely showing a variety of foods (as Havermans and Brondel did) does not mean that individuals necessarily interpret the situation as having the opportunity to taste that variety. Unfortunately, Havermans and Brondel failed to assess their participants' expectations regarding the presented food variety. Perhaps the participants had not even noticed the variety. A series of experiments conducted by Kahn and Wansink (2004) do suggest that perceived variety affects the variety effect. In this series of experiments, Kahn and Wansink manipulated assortment size and organization of M&M's or jellybeans and found that it influenced intake to the degree the assortment actually impacted perceived variety. When more variety is perceived, intake tends to increase.

With regard to the actual eating context, Garcia-Burgos et al. (2015) examined whether SSS is affected by the context in which a food is consumed. They gave participants a herbal tea beverage to drink ad libitum, either in a laboratory (novel eating context) or in a cafeteria (natural eating context), assessing SSS for the flavour and smell of the drink. They found that the magnitude of SSS for smell (but not for flavour) was smaller in the cafeteria than in the laboratory, suggesting that olfactory SSS is sensitive to the context in which one eats a food.

Taken together, the evidence gathered thus far on the influence of the meal situation suggests that attentional focus can indeed affect SSS (as well as the variety effect). Evidence for an effect of the actual eating context (including perceived food variety) is, however, lacking.

This dissertation

Both SSS and the variety effect have received much research attention as they are important determinants of the amount of food people eat. However, many questions regarding potential moderators and underlying mechanisms are still left unanswered. For example, we still don't know whether SSS is context-dependent (i.e., does a change of context during an eating bout abolish SSS?), whether SSS can be influenced top-down (e.g., do certain beliefs or mindset affect the degree of SSS?), to what degree SSS and the variety effect are truly two sides of the same coin, and how relevant SSS and the variety effect are in directing individuals' food choice. The main aim of this dissertation was therefore three-fold: (1) to further elucidate how SSS and the variety effect are related, (2) to further our understanding of factors affecting SSS, and (3) to determine the relevance and potential of SSS and the variety effect in guiding food selection. The studies in this dissertation provide us with a better understanding of important mechanisms that regulate our appetite and satiation. These novel insights are valuable for the development of healthy, enjoyable, and satisfying meals.

Chapter 2 describes an experiment in which the presumed mechanism between SSS and the variety effect was investigated. Participants attended two laboratory sessions in which they ate a 'meal' (using a signalled exposure procedure: look-smell-taste-swallow) consisting of 10 bite-sized food portions, that was either low in variety or high in variety. The low variety meal consisted of 5 bite-sized portions of only two food items (food A and B: A-B-A-B-A-B-A-B-A-B), whereas the high variety meal consisted of 5 bite-sized portions of food A and a single portion of 5 other foods (B, C, D, E, and F: A-B-A-C-A-D-A-E-A-F). Participants tasted and evaluated their liking of and the desire to eat the six foods included in the meals plus two other 'uneaten' foods (G and H) to establish the development of SSS for both meals and its individual components. We expected SSS to develop for food A to the same extent in both meals (irrespective of overall level of meal variety) because it depends mainly on orosensory exposure. In line with this, for food B, SSS would be stronger when 5 portions of it were consumed (low variety meal) than when only 1 portion of it was consumed (high variety meal).

Chapter 3 describes a study in which SSS and the variety effect were replicated and the context-dependence of SSS was explored. In the study, participants ate a food until pleasantly full after which they received a second course of the same or a different food, in the same or a different context (i.e., room). In addition, before and after the first course, participants evaluated their liking of and desire to eat the consumed food as well as seven uneaten foods to test for SSS. We expected that: SSS would develop for the food eaten in the first course; introducing food variety (i.e., a different food in the second course) would increase intake of the second course; and switching to a different context for the second course would also increase intake in the second course. Furthermore, we expected that both receiving a different food and changing the context would lead to an even larger increase in intake than only changing the food or context due to a synergistic effect.

Chapter 4 investigates the influence of cognition (beliefs) on SSS and food intake. In this study participants' expectations of the satiating capacity of a meal (a pasta salad) were manipulated. Participants in the study consumed a pasta salad twice (ad libitum), once accompanied by a label informing them that the pasta salad would be filling them up quickly ('filling'), and once accompanied by a label informing them that the pasta salad would not fill them up quickly ('light'). To test for SSS, the participants indicated their liking of and desire to eat the pasta salad and seven control foods before and after ad libitum consumption of the pasta salad. As SSS is an important factor in meal termination (Rolls, 2018; Hetherington & Havermans, 2013), we expected a similar level of SSS in both conditions but with a marked difference in intake (i.e., more intake when the pasta salad was accompanied by the 'light' label).

Chapter 5 describes two studies examining the importance of SSS and the variety effect in consumers' expressed product preferences. In two online choice-experiments, the relative importance of complexity and variety (Study 1), and of variety and portion size (Study 2) was established for ice cream products in a Dutch sample and a sample of American consumers. Just as SSS is one of the primary factors involved in meal termination, we expected that food variety would be the primary factor in determining food selection. More variety promises longer enjoyment. Specifically, we expected that variety would be the main driver of product selection when compared to complexity and portion size, in both a Dutch and American sample.

Chapter 6 provides a summary and general discussion of the main results of the studies that are part of this dissertation. It comprises a discussion of the theoretical and practical implications of the results presented in chapters 2-5 and of the results from a pilot study I conducted. Furthermore, suggestions for future research on SSS and the variety effect are presented.

References

Bell, E. A., Roe, L. S., & Rolls, B. J. (2003). Sensory-specific satiety is affected more by volume than by energy content of a liquid food. *Physiology & Behavior*, *78*, 593–600. https://doi.org/10.1016/S0031-9384(03)00055-6

Bellisle, F., & Blundell, J. E. (2013). Satiation, satiety: concepts and organisation of behaviour. In *Satiation, Satiety and the Control of Food Intake* (pp. 3–11). Woodhead Publishing Limited. https://doi.org/10.1533/9780857098719.1.3

Bellisle, F., & Le Magnen, J. (1980). The analysis of human feeding patterns: the edogram. *Appetite*, *1*(2), 141–150. https://doi.org/10.1016/S0195-6663(80)80018-3

Bolhuis, D. P., & Forde, C. G. (2020). Application of food texture to moderate oral processing behaviors and energy intake. *Trends in Food Science and Technology*, *106*, 445–456. https://doi.org/10.1016/j.tifs.2020.10.021

Blundell, J. E., Rogers, P. J., & Hill, A. J. (1987). Evaluating the satiating power of foods. Implications for acceptance and consumption. In J. Solms, D. A. Booth, R. M. Pangbourne, & O. Raunhardt (Eds.), *Food acceptance and nutrition* (pp. 205–219). Academic Press.

Braude, L., & Stevenson, R. J. (2014). Watching television while eating increases energy intake. Examining the mechanisms in female participants. *Appetite*, *76*, 9–16. https://doi.org/10.1016/j.appet.2014.01.005

Brondel, L., Romer, M., Van Wymelbeke, V., Walla, P., Jiang, T., Deecke, L., & Rigaud, D. (2007). Sensory-specific satiety with simple foods in humans: no influence of BMI? *International Journal of Obesity*, *31*, 987–995. https://doi.org/10.1038/sj.ijo.0803504

Cabanac, M. (1971). Physiological role of pleasure. *Science*, *173*(4002), 1103–1107.

Cabanac, M. (1979). Sensory pleasure. *The Quarterly Review of Biology*, *54*(1), 1–29.

Chung, S. J., & Vickers, Z. (2007). Influence of sweetness on the sensory-specific satiety and long-term acceptability of tea. *Food Quality and Preference*, *18*(2), 256–264. https://doi.org/10.1016/j.foodqual.2005.12.002

De Graaf, C. (2012). Texture and satiation: the role of oro-sensory exposure time. *Physiology & Behavior*, *107*(4), 496–501. https://doi.org/10.1016/j.physbeh.2012.05.008

Embling, R., Pink, A. E., Gatzemeier, J., Price, M., Lee, M. D., & Wilkinson, L. L. (2021). Effect of food variety on intake of a meal: a systematic review and meta-analysis. *The American Journal of Clinical Nutrition*, *113*(3), 716-741. https://doi.org/10.1093/ajcn/nqaa352

Garcia-Burgos, D., Secchiari, F., & Calviño, A. (2015). Is sensory-specific satiety for a bitter-sweet infusion modulated by context? *Physiology & Behavior*, *140*, 180–187. https://doi.org/10.1016/j.physbeh.2014.12.035

Havermans, R. C., & Brondel, L. (2013). Satiety in face of variety: on sensory-specific satiety and perceived food variety. *Food Quality and Preference*, *28*(1), 161–163. https://doi.org/10.1016/j.foodqual.2012.07.009

Havermans, R. C., Geschwind, N., Filla, S., Nederkoorn, C., & Jansen, A. (2009). Sensory-specific satiety is unaffected by manipulations of flavour intensity. *Physiology & Behavior*, *97*(3–4), 327–333. https://doi.org/10.1016/j.physbeh.2009.02.030

Havermans, R. C., Roefs, A., Nederkoorn, C., & Jansen, A. (2012). No rapid recovery of sensory-specific satiety in obese women. *Flavour*, *1*, 1- 5. https://doi.org/10.1186/2044-7248-1-5

Hetherington, M., & Havermans, R. C. (2013). Sensory-specific satiation and satiety. In J. E. Blundell & F. Bellisle (Eds.), *Satiation, satiety and the control of food intake. Theory and practice* (pp. 253–269). Woodhead Publishing Ltd. https://doi.org/10.1533/9780857098719.4.253

Hetherington, M. M., & Rolls, B. J. (1996). Sensory-specific satiety: theoretical frameworks and central characteristics. In E. D. Capaldi (Ed.), *Why we eat what we eat: the psychology of eating.* (pp. 267–290). American Psychological Association. https://doi.org/10.1037/10291-010

Hollis, J. H., & Henry, C. J. K. (2007). Sensory-specific satiety and flavor amplification of foods. *Journal of Sensory Studies*, *22*(4), 367–376. https://doi.org/10.1111/j.1745-459X.2007.00110.x

Hsiao, S., & Tuntland, P. (1971). Short-term satiety signals generated by saccharin and glucose solutions. *Physiology & Behavior*, *7*(2), 287–289. https://doi.org/10.1016/0031-9384(71)90303-9

Johnson, J., & Vickers, Z. (1992). Factors influencing sensory-specific satiety. *Appetite*, *19*(1), 15–31. https://doi.org/10.1016/0195-6663(92)90233-V

Jones, E. C. (1970). Effects of ingesting nonnutritive sweet substances on subsequent sucrose consumption. *Psychonomic Science*, *21*(1), 23–24. https://doi.org/10.3758/BF03332416

Kahn, B. E., & Wansink, B. (2004). The influence of assortment structure on perceived variety and consumption quantities. *Journal of Consumer Research*, *30*(4), 519–533. https://doi.org/10.1086/380286

Katz, D. (1935). Some fundamental laws of the psychology of needs: hunger. *Journal of Personality*, *3*(4), 312–326. https://doi.org/10.1111/j.1467-6494.1935.tb02013.x

Le Magnen, J. (1999). Increased food intake induced in rats by changes in the satiating sensory input from food. *Appetite*, *33*(1), 33–35. https://doi.org/10.1006/appe.1999.0257

Maier, A., Vickers, Z., & Inman, J. J. (2007). Sensory-specific satiety, its crossovers, and subsequent choice of potato chip flavors. *Appetite*, *49*(2), 419–428. https://doi.org/10.1016/j.appet.2007.02.006

McCrory, M. A., Burke, A., & Roberts, S. B. (2012). Dietary (sensory) variety and energy balance. *Physiology & Behavior*, *107*(4), 576–583. https://doi.org/10.1016/j.physbeh.2012.06.012

Meengs, J. S., Roe, L. S., & Rolls, B. J. (2012). Vegetable variety: an effective strategy to increase vegetable intake in adults. *Journal of the Academy of Nutrition and Dietetics*, *112*(8), 1211–1215. https://doi.org/10.1016/j.jand.2012.05.013

Meillon, S., Thomas, A., Havermans, R., Pénicaud, L., & Brondel, L. (2013). Sensory-specific satiety for a food is unaffected by the ad libitum intake of other foods during a meal: is SSS subject to dishabituation? *Appetite*, *63*, 112–118. https://doi.org/10.1016/j.appet.2012.12.004

Meiselman, H. L., De Graaf, C., & Lesher, L. L. (2000). The effects of variety and monotony on food acceptance and intake at a midday meal. *Physiology & Behavior*, *70*(1–2), 119–125. https://doi.org/10.1016/S0031-9384(00)00268-7

Morrison, G. R. (1974). Alterations in palatability of nutrients for the rat as a result of prior tasting. *Journal of Comparative and Physiological Psychology*, *86*(1), 56–61. https://doi.org/10.1037/h0035961

Mugford, R. A. (1977). External influences on the feeding of carnivores. In M. R. Kare & O. Maller (Eds.), *The Chemical Senses and Nutrition* (pp. 25–50). Academic Press Inc. (London) Limited.

Nolan, L. J., & Hetherington, M. M. (2009). The effects of sham feeding-induced sensory specific satiation and food variety on subsequent food intake in humans. *Appetite*, *52*(3), 720–725. https://doi.org/10.1016/j.appet.2009.03.012

Piqueras-Fiszman, B., & Spence, C. (2014). Colour, pleasantness, and consumption behaviour within a meal. *Appetite*, *75*, 165–172. https://doi.org/10.1016/j.appet.2014.01.004

Pliner, P., Polivy, J., Herman, C. P., & Zakalusny, I. (1980). Short-term intake of overweight individuals and normal weight dieters and non-dieters with and without choice among a variety of foods. *Appetite*, *1*(3), 203–213. https://doi.org/10.1016/S0195-6663(80)80029-8

Ramaekers, M. G., Boesveldt, S., Gort, G., Lakemond, C. M. M., Van Boekel, M. A. J. S., & Luning, P. A. (2014). Sensory-specific appetite is affected by actively smelled food odors and remains stable over time in normal-weight women. *The Journal of Nutrition*, *144*(8), 1314–1319. https://doi.org/10.3945/jn.114.192567

Raynor, H. A., & Epstein, L. H. (2001). Dietary variety, energy regulation, and obesity. *Psychological Bulletin*, *127*(3), 325–341. https://doi.org/10.1037/0033-2909.127.3.325

Raynor, H. A., & Vadiveloo, M. (2018). Understanding the relationship between food variety, food intake, and energy balance. *Current Obesity Reports*, *7*, 68–75. https://doi.org/10.1007/s13679-018-0298-7

Remick, A. K., Polivy, J., & Pliner, P. (2009). Internal and external moderators of the effect of variety on food intake. *Psychological Bulletin*, *135*(3), 434–451. https://doi.org/10.1037/a0015327

Rogers, P. J., Drumgoole, F. D. Y., Quinlan, E., & Thompson, Y. (2021). An analysis of sensory-specific satiation: food liking, food wanting, and the effects of distraction. *Learning and Motivation*, *73*, 101688. https://doi.org/10.1016/j.lmot.2020.101688

Rogers, P. J., Ferriday, D., Irani, B., Hoi, J. K. H., England, C. Y., Bajwa, K. K., & Gough, T. (2020). Sweet satiation: acute effects of consumption of sweet drinks on appetite for and intake of sweet and non-sweet foods. *Appetite*, *149*, 104631. https://doi.org/10.1016/j.appet.2020.104631

Rolls, B. J. (1979). How variety and palatability can stimulate appetite. *Nutrition Bulletin*, *5*(2), 78–86. https://doi.org/10.1111/j.1467-3010.1979.tb00838.x

Rolls, B. J. (1986). Sensory-specific satiety. *Nutrition Reviews*, *44*(3), 93–101. https://doi.org/10.1111/j.1753-4887.1986.tb07593.x

Rolls, B. J., & McDermott, T. M. (1991). Effects of age on sensory-specific satiety. *American Journal of Clinical Nutrition*, *54*(6), 988–996. https://doi.org/10.1093/ajcn/54.6.988

Rolls, B. J. (2018). The role of portion size, energy density, and variety in obesity and weight management. In T. A. Wadden & G. A. Bray (Eds.), *Handbook of Obesity Treatment* (Second Edition, pp. 93-104). The Guilford Press.

Rolls, B. J., Rolls, E. T., Rowe, E. A., & Sweeney, K. (1981). Sensory specific satiety in man. *Physiology & Behavior*, *27*(1), 137–142. https://doi.org/10.1016/0031-9384(81)90310-3

Rolls, B. J., Rowe, E. A., Rolls, E. T., Kingston, B., Megson, A., & Gunary, R. (1981). Variety in a meal enhances food intake in man. *Physiology & Behavior*, *26*(2), 215–221. https://doi.org/10.1016/0031-9384(81)90014-7

Rolls, E. T., & Rolls, J. H. (1997). Olfactory sensory-specific satiety in humans. *Physiology & Behavior*, *61*(3), 461–473. https://doi.org/10.1016/S0031-9384(96)00464-7

Romer, M., Lehrner, J., Van Wymelbeke, V., Jiang, T., Deecke, L., & Brondel, L. (2006). Does modification of olfacto-gustatory stimulation diminish sensory-specific satiety in humans? *Physiology & Behavior*, *87*(3), 469–477. https://doi.org/10.1016/j.physbeh.2005.11.015

Shaw, J. S. (1973). *The influence of type of food and method of presentation on human eating behavior* [Unpublished doctoral dissertation]. University of Pennsylvania.

Smeets, A. J. P. G., & Westerterp-Plantenga, M. S. (2006). Oral exposure and sensory-specific satiety. *Physiology & Behavior*, *89*(2), 281–286. https://doi.org/10.1016/j.physbeh.2006.06.011

Vadiveloo, M., Principato, L., Morwitz, V., & Mattei, J. (2019). Sensory variety in shape and color influences fruit and vegetable intake, liking, and purchase intentions in some subsets of adults: a randomized pilot experiment. *Food Quality and Preference*, *71*, 301–310. https://doi.org/10.1016/j.foodqual.2018.08.002

Vickers, Z. (2017). Satiety and liking intertwined. In B. Tepper & M. Yeomans (Eds.), *Flavor, Satiety and Food Intake* (First Edit, pp. 13–34). John Wiley & Sons Ltd. https://doi.org/10.1002/9781119044970.ch2

Vickers, Z., & Holton, E. (1998). A comparison of taste test ratings, repeated consumption, and post-consumption ratings of different strengths of iced tea. *Journal of Sensory Studies*, *13*, 199–212.

Weenen, H., Stafleu, A., & De Graaf, C. (2005). Dynamic aspects of liking: post-prandial persistence of sensory specific satiety. *Food Quality and Preference*, *16*(6), 528–535. https://doi.org/10.1016/j.foodqual.2004.11.002

Weijzen, P. L. G., Zandstra, E. H., Alfieri, C., & De Graaf, C. (2008). Effects of complexity and intensity on sensory specific satiety and food acceptance after repeated consumption. *Food Quality and Preference*, *19*(4), 349–359. https://doi.org/10.1016/j.foodqual.2007.11.003

Wilkinson, L. L., & Brunstrom, J. M. (2016). Sensory specific satiety: more than “just” habituation? *Appetite*, *103*, 221–228. https://doi.org/10.1016/j.appet.2016.04.019

Young, P. T. (1940). Reversal of food preferences of the white rat through controlled pre-feeding. *The Journal of General Psychology*, *22*(1), 33–66. https://doi.org/10.1080/00221309.1940.10544318

Zoon, H. F. A., De Graaf, C., & Boesveldt, S. (2016). Food odours direct specific appetite. *Foods*, *5*(12). https://doi.org/10.3390/foods5010012

2

Exploring the mechanism of within-meal variety and sensory-specific satiation

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Abstract

Food variety has been shown to enhance consumption, and it has repeatedly been proposed that this variety effect might operate by delaying the development of sensory-specific satiation (SSS; a relative decrease in pleasantness of a specific food as it is consumed). This study aimed to advance our understanding of the presumed relationship between SSS and food variety. Participants (*N* = 30) received two meals on two separate days, one consisting of only two food items (A and B; low variety), and the other comprising six foods (A, B, C, D, E, and F; high variety). Each meal comprised signalled exposure (look-smell-taste-swallow) to a total of 10 bite-size portions: 5 portions of foods A and B in the low variety condition, and 5 portions of A and a single portion of foods B, C, D, E, and F in the high variety condition. Participants tasted 8 food items before and after each meal (i.e., the 6 foods included in the meals plus 2 more unconsumed foods G and H). It was hypothesized that SSS for food A would develop irrespective of overall meal variety, but that SSS for food B would be smaller in the high variety session. The results of this study were in accordance with this hypothesis: strong SSS was present for food A in both meal varieties, while it was absent for food B in the high variety meal. This indicates that meal variety does not necessarily affect SSS. SSS is strictly determined by degree and timing of sensory exposure to a food. Exposure time should therefore be targeted when developing strategies to influence the development of sensory-specific satiation, which in its turn can affect food intake.

Introduction

When a food is eaten, the pleasantness of this food decreases during its consumption, relative to other unconsumed foods (Rolls, Rolls, et al., 1981). This phenomenon is referred to as ‘sensory-specific satiation’ (SSS), which is defined as: ‘the changing hedonic response to the sensory properties of a particular food as it is consumed’ (Rolls, 1986, p. 95). SSS has been extensively studied and is thought to play an important role in eating behaviour, as it affects the amount of food consumed in a meal (Rolls, 1986; Rolls, 2018). It both prompts the ending of an eating bout and promotes consumption of a varied meal (Hetherington & Rolls, 1996). Conversely, it is thought that meal variety delays the development of SSS (Brondel, Lauraine, et al., 2009), and consequently increases food intake (Hetherington et al., 2006; Brondel, Romer, et al., 2009).

Food variety has indeed repeatedly been shown to increase consumption (see e.g., Raynor & Osterholt, 2012; McCrory et al., 2012; Rolls, Rowe, et al., 1981; Pliner et al., 1980), generally referred to as ‘the variety effect’ (Rolls, Rowe, et al., 1981; Pliner et al., 1980). In several experiments, conducted by Hetherington et al. (2006) and Brondel, Romer, et al. (2009), both the effect of food variety on meal intake, and its influence on the development of SSS were investigated. The results of these experiments showed an increased food intake and attenuated SSS when a variety of foods was consumed, and thus provide strong evidence for SSS as mechanism through which meal variety enhances consumption (Rolls, 1981; Rolls, 2007; Raynor & Epstein, 2001).

There is evidence to suggest that different levels of food variety have commensurate effects on consumption (Epstein et al., 2010; see also Brondel, Lauraine, et al., 2009; Rolls et al., 1984; Rolls, 1986). Previous studies suggest that small changes of texture or flavour could be enough to create variety in a meal, and consequently increase meal intake (Epstein et al., 2010; Rolls et al., 1982; but see: Rolls, Rowe, et al., 1981). Results of experiments in which more properties of the foods were varied showed increases in intake levels as high as 60% (Rolls, 1986; Rolls et al., 1984; see also Rolls, Rowe, et al., 1981). Taking all results of the various studies investigating the effect of variety on food intake into account, these seem to indicate a dose-response relationship between food variety and food intake (i.e., more variety results in more food intake).

When considering the evidence of this dose-response relationship between food variety and consumption, it makes sense to presume that the relationship between food variety and SSS also resembles a dose-response relationship (i.e., when level of variety increases, less SSS occurs). However, it is more commonly assumed that SSS is primarily determined by the intensity and frequency of orosensory exposure to a food (see e.g., De Graaf, 2012). Smeets and Westerterp-Plantenga (2006) demonstrated the importance of orosensory exposure for the development of SSS using a modified sham feeding (MSF) paradigm. Participants were tested on three test days, on which they received water, MSF, or a meal. In the MSF condition, the participants were asked to chew the food and to expectorate it when they would normally swallow it. The study results showed SSS for salad both when participants ate the salad and when they were sham fed the salad, indicating the importance of orosensory exposure. This implies that the same degree of exposure to a food within differently varied meals will nonetheless generate an equal degree of SSS for this food. In other words, meal variety might directly undermine SSS, but it is also possible that it does so only indirectly by reducing the degree of overall exposure to any one of the meal components. The present study aimed to disentangle these two potential effects of variety on SSS by investigating the effects of different levels of food variety on SSS for different components of a meal.

In this study, we examined the development of SSS for different components of a meal in two meals that differed in their overall level of food variety, using a signalled exposure procedure (described in detail in the Methods section below). Two meals were offered to participants consisting of ten food portions: a ‘low variety’ meal (LV session) which consisted of five portions of two foods (A and B) that were alternated (ABABABABAB), or a ‘high variety’ meal (HV session) consisting of five portions of food A, and one portion of five other food items (ABACADAEAF). Before and after both meals, participants tasted and rated eight different food items (A-H, which included the items that composed the meals). We hypothesized that food A would show a decrease in pleasantness relative to unconsumed foods G and H, irrespective of type of meal (low variety or high variety), because the orosensory exposure to food A is equal in both meal varieties. We further hypothesized that SSS for food B would be delayed in the high variety meal, since it is consumed only once in this meal as opposed to 5 times in the low variety meal. We also planned to explore whether post-meal liking of food items G and H would be larger in the low variety meal as opposed to the high variety meal, due to a larger satiation for the foods comprising the meal (A and B). Satiation in this paper refers to reduced pleasure for a food consumed relative to unconsumed foods. As high food variety might undermine this satiation we hypothesized more satiation for a low variety meal. Furthermore, we expected that with more satiation for a meal, unconsumed foods might become better liked as the result of a positive hedonic contrast.

Methods

The study was approved by the Maastricht University Ethical Research Committee of Psychology and Neuroscience (reference number ERCPN- 195_04_06_2018) and preregistered on 15/8/2018 on the Open Science Framework (https://osf.io/b8s75/).

Participants

In order to estimate the number of participants needed in the study, a sample size calculation was performed using G*Power 3.1 (Faul et al., 2007) for a repeated measures ANOVA (within factors), using an α rejection criterion of 0.05 and 0.80 (1-β) power, and an average correlation of rho = 0.50 between the repeated measures for 4 within subject measurements to detect a medium effect (f = 0.25). There were no prior studies to inform an effect size estimate for our study. Therefore, we decided to include a sufficient number of participants to be able to detect at least a medium effect. The power calculation indicated that a minimum of 24 participants was required to be able to find such an effect. We aimed to recruit and test a sample of 30 participants.

Participants in this experiment were excluded if they were aged under 18 or above 50 years old. Exclusion of participants aged above 50 years was based on prior study results suggesting that the variety effect is stronger in younger people than in older people (Remick et al., 2009). Participants were also excluded if they had prior knowledge regarding sensory-specific satiation, or if they participated in an experiment concerning sensory-specific satiation before. Exclusion criteria further comprised physical or mental health conditions that might affect eating behaviour; a history of cancer, gastrointestinal illness, celiac disease, dental surgery within the last three months, COPD, diabetes, eating disorders, chemosensory dysfunction, smoking addiction, difficulties with swallowing/eating, hypersensitivity or allergies to the food products used in the study or dislike of the food items, a vegan/vegetarian diet, and pregnancy or breastfeeding.

Recruitment took place via convenience sampling (e.g., advertisements, posters, and flyers). Before participation in the study, candidate participants were screened to make sure they met the inclusion criteria and were informed about the food items included in the study. They were also asked whether they disliked the food items. When included, participants were given the necessary information about participation (i.e., the experimental procedure, though not the aim and hypothesis of the experiment). In case a participant had a cold on the day of a lab session, the session was rescheduled. The aim and hypothesis of the experiment were disclosed after the data collection was completed.

A total of 32 subjects participated in the study. One participant's data was excluded from the analyses because this participant was tested in a different lab room than all the other participants were tested in. Another participant did not follow the instructions. Data from this participant was also excluded from further analyses. Of the 30 participants remaining (aged between 18 and 47 years old; M = 26.30, SD = 8.36), two were male and 28 were female.

Procedure, measurements and design

The participants of the study were tested in groups of maximum three participants during two tasting/eating sessions, session LV and HV (in counterbalanced order; half of the participants started with session LV and the other half with session HV) on different days separated by at least one week. See Table 1 for the exact procedures of both sessions.

The eating sessions took place at the laboratory, scheduled between noon and 6:00 p.m. Participants were instructed to eat something small two hours prior to the scheduled laboratory session and to refrain from eating and drinking (except water) during the two hours prior to the session. Upon arrival at the laboratory for the first session, the participants were informed about the procedure of the experiment, they signed a consent form, and completed a demographics questionnaire containing questions about age, gender, and educational level (low, middle, or high). Both sessions then followed equal procedures, which are described next.

Table 1. Experimental design and procedure.

	Time →		
Session LV	Taste test 1	Signalled exposure of A-B-A-B-A-B-A-B-A-B	Taste test 2
Session HV	Taste test 1	Signalled exposure of A-B-A-C-A-D-A-E-A-F	Taste test 2

Note. A denotes a cube of cheese, B denotes cervelat, C denotes toast with chicken-curry salad, D denotes meatball, E denotes walnut, and F denotes toast with egg salad.

In each of the two sessions, the participants completed a questionnaire that checked whether they complied with the request not to eat during the two hours prior to the session, and whether they were having a cold. None of the participants indicated to have eaten during the two hours prior to the session or to be unable to smell/taste due to a cold. The participants were also asked to rate their hunger and thirst level on a 100-mm visual analogue scale (VAS), ranging from 0 (not at all hungry/thirsty) to 100 (extremely hungry/thirsty). They were instructed not to engage in activities during the sessions that could distract them from the instructed tasks (e.g., using their phone or reading a book). Next, they were presented with eight food items: meatball, toast with egg salad, a cube of cheese, walnut, tomato and cucumber on a stick, toast with chicken-curry salad, cervelat, and Tuc cracker (see section Foods for characteristics of the food items). The participants were instructed to taste the food items and rate their pleasantness ('How pleasant do you find the flavour of this food right now?'), and their desire to eat the foods ('How strong is your desire to eat this food right now?') on a VAS ranging from -10 (not at all), through 0 (neutral), to 10 (extremely). The eight food items were all given a random three-digit number and were tasted by the participant one by one.

In both sessions, the participants then received one of the two meal varieties to consume. The test meals were matched on calorie content; the low variety (LV) meal contained approximately 284 kilocalories, and the high variety (HV) meal contained approximately 281 kilocalories. The exact compositions of the meal varieties are shown in Table 2 and 3. The participants were asked to consume the meal using a signalled exposure procedure. This procedure has been shown to successfully induce satiation (see e.g., Havermans, Geschwind, et al., 2009; Brunstrom & Mitchell, 2006; Havermans et al., 2010), and allows for control over the volume consumed by participants, enabling us to evaluate the development of SSS at fixed time points. In a signalled exposure procedure, participants are asked to take a portion of a food item, then look at it for 10 seconds, smell it for 10 seconds, to chew and experience the mouthfeel of it for 10 seconds, and eventually to swallow it (Havermans et al., 2010). In session LV, the participant received five portions of food A (a cube of cheese) and five portions of food B (cervelat). Food A and B were alternated with each exposure (ABABABABAB). In session HV, the participant received five bite sized portions of food A (a cube of cheese), and one portion of food B (cervelat), C (toast with chicken-curry salad), D (meatball), E (walnut), and F (toast with egg salad). The total meal variety in session HV thus comprised six foods, but again with five exposures to food A (ABACADAEAF).

After completion of the meal, participants in each session again tasted and evaluated the eight aforementioned food items that were tasted in the first taste test. The procedures of the first and second taste test were equal. During each session, participants had free access to tap water to clear the palate in between tasting the different food items. Upon completing both sessions, participants were asked what they thought the experiment was about, and received a €5 voucher for remuneration.

Table 2. Meal composition and calorie content of low variety meal (LV).

Meal contents	Amount	Kilocalories
Cheese cubes (6g per piece)	5 pieces	112.5
Cervelat (6.5g per piece)	5 pieces	171.3
Total		283.8

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Table 3. Meal composition and calorie content of high variety meal (HV).

Meal contents	Amount	Kilocalories
Cheese cubes (6g per piece)	5 pieces	112.5
Cervelat (6.5g per piece)	1 piece	34.3
Toast with egg salad:		
- Toast (3.25g per piece)	1 piece	15.4
- Egg salad (4.5g per piece)	1 piece	13.5
Toast with chicken curry salad:		
- Toast (3.25g per piece)	1 piece	15.4
- Chicken curry salad (4.5g per piece)	1 piece	10.8
Walnut (3.5g per piece)	1 piece	24.8
Meatball (16.6g per piece)	1 piece	54.3
Total		281

Foods

The food items used in this study were: cheese cubes (AH Goudse kaas jong belegen 48+ blokjes: 375 kcal per 100 g), meatball (Kips Hollandse gehaktballetjes: 327 kcal per 100 g), toast (Haust Snack cups naturel rond: 473 kcal per 100 g) with egg salad (Johma Eisalade: 299 kcal per 100 g), walnut (708 kcal per 100 g), tomato (30 kcal per 100 g) and cucumber (13 kcal per 100 g) on a stick, toast (Haust Snack cups naturel rond: 473 kcal per 100 g) with chicken-curry salad (Johma Kip-kerrie salade: 241 kcal per 100 g), cervelat (Compaxo Amigo's naturel: 527 kcal per 100 g), and Tuc cracker (LU Tuc crackers minibites original: 485 kcal per 100 g) (RIVM, 2016).

Data analysis

The data for the relevant analyses were first screened for error outliers (e.g., due to incorrect data entry), interesting outliers (e.g., unexpected extreme values not due to error), and influential outliers (Aguinis et al., 2013). We planned to correct or remove error outliers from the data set, to remove interesting outliers from the proposed analyses and study these separately, and to decrease the influence of spurious outliers by winsorizing extreme values (i.e., by clipping the outlier to match the value of the next highest or lowest data point). Outliers were considered potentially influential at mean ± 3 *SD*, which resulted in two outliers being winsorized. None of the outliers were due to error in data entry.

To test the influence of the different levels of variety on development of SSS for food A and B, difference scores were calculated for each session between pre-test (taste test 1) and post-test (taste test 2) ratings of food pleasantness and desire to eat the foods for food A and B, and for the two food items which were unconsumed in both sessions (control foods G and H; tomato and cucumber on a stick and Tuc cracker). The difference scores for the unconsumed foods were averaged into a single difference score (note that these foods are the control foods in all reported ANOVAs). The pleasantness scores were used as primary outcome variable for determining SSS. Two separate 2 (session: LV or HV) x 2 (food: eaten or control) repeated measures analysis of variance (ANOVA; type III sums of squares) were performed, to examine development of SSS for foods A and B. We originally intended to compare the pleasantness difference score of food B (session LV) with the mean pleasantness difference of foods BCDEF (session HV). We decided to deviate from the preregistered analysis for food B, because testing the difference in change in liking of B (LV) vs. B (HV) is a more straightforward comparison, that refers to the exact same food in both meal varieties. The originally planned analyses can be found in our preregistration, available on the Open Science Framework (https://osf.io/b8s75/).

The potential effects of different levels of variety on the difference scores of the unconsumed foods G and H were also explored. We altered the analysis for the exploratory hypothesis from the preregistered analysis because we are convinced that with a less extensive test the hypothesis can also be tested. The originally intended analysis can be found in our online preregistration on the Open Science Framework. We used the post-hoc tests of the second ANOVA (for food B) to determine whether there was a significant difference in change in liking for the unconsumed foods between the sessions.

For all ANOVAs generalized eta-squared (η^2_G) is reported as effect size, which is the recommended effect size statistic for repeated measures designs (Bakeman, 2005). All analyses were performed in R, using the RStudio® software package (RStudio Team, 2016) and the packages 'pastecs', 'ggplot2', 'ez', 'reshape', 'reshape2', and 'plyr'. All effects are reported as significant at $p < .05$. The anonymized raw data, the excel file sheets we used for the data analyses and the R scripts are available on the Open Science Framework (https://osf.io/b8s75/).

Results

Mean pre-prandial hunger did not significantly differ between sessions LV ($M = 5.99$, $SD = 2.15$) and HV ($M = 5.89$, $SD = 2.18$), $t(29) = -0.20$, $p = .84$. Mean pre-prandial indication of thirst also did not differ between sessions LV ($M = 5.59$, $SD = 1.48$) and HV ($M = 5.99$, $SD = 1.58$), $t(29) = 1.02$, $p = .32$. The pre- and post-test liking ratings for the foods used in the ANOVAs are shown in Table 4. A supplemental table showing the initial liking scores for all foods is available on the Open Science Framework (https://osf.io/b8s75/).

Table 4. Means for pretest and post-test liking ratings for food A, B, meal and control foods for both sessions. Values in parentheses represent SD.

	Low variety		**High variety**	
	Pretest	**Post-test**	**Pretest**	**Post-test**
Cheese cubes (A)	4.51 (3.60)	1.69 (4.54)	4.05 (4.15)	1.54 (4.43)
Cervelat (B)	2.13 (4.27)	-1.84 (4.34)	1.34 (4.19)	0.40 (4.43)
Meal	3.32 (3.27)	-0.07 (3.35)	3.54 (2.13)	2.28 (2.36)
Control foods (G & H)	4.61 (3.09)	5.00 (2.68)	4.77 (2.53)	4.99 (2.32)

The two-way repeated measures ANOVA with Food (A or control) and Variety (low or high) as factors revealed a significant main effect of Food on the difference scores in liking [$F(1, 29) = 20.24$, $p < .001$, $\eta^2_G = 0.23$], indicating SSS for Food A in both sessions. There was no significant effect of Variety, $F(1, 29) = 0.08$, $p = .78$, and no significant interaction effect, $F(1, 29) = 0.33$, $p = .57$. The results of the 2 x 2 ANOVA with Food (B or control) and Variety (low or high) as factors indicated a significant main effect of Food [$F(1, 29) = 35.01$, $p < .001$, $\eta^2_G = 0.23$], Variety [$F(1, 29) = 10.17$, $p < .01$, $\eta^2_G = 0.08$], and a significant interaction effect [$F(1, 29) = 10.69$, $p < .01$, $\eta^2_G = 0.09$]. Post-hoc analysis of the interaction (Bonferroni corrected) showed a significant difference for change in liking between food B and the control foods in session LV ($p < .001$), but not in session HV ($p = .71$), which indicates that SSS for food B was only present in session LV. It further revealed that there was no significant difference in change in liking for the control foods between sessions LV and HV ($p = 1.00$). Figure 1 shows the mean change in liking scores for foods A, B, the overall meal, and the unconsumed control foods.

Exploratory analyses

Overall meal SSS was explored with a two-way repeated measures ANOVA with Food (meal or control) and Variety (low or high) as factors to examine whether level of variety affected overall meal SSS. The results showed a significant main effect of Food [$F(1, 29) = 36.40$, $p < .001$, $\eta^2_G = 0.31$] and Variety [$F(1, 29) = 7.29$, $p < .05$, $\eta^2_G = 0.07$], and a significant interaction effect [$F(1, 29) = 14.06$, $p < .001$, $\eta^2_G = 0.07$]. Post-hoc analysis revealed a significant difference for change in liking between the meal and control foods in both session LV ($p < .001$) and session HV ($p < .05$), but also indicated a significant difference in change in liking for the meal in session HV and LV ($p < .001$). This indicates that SSS was present for the meal in both meal varieties, however, the decrease in liking for the low variety meal was larger than the decrease in liking for the high variety meal, as one would expect (see Figure 1 for mean differences of the liking scores for both meal varieties).

An exploratory analysis for the difference scores for desire was conducted to check whether these follow the same pattern as the liking scores. The exploratory analysis (two-way ANOVA with Food (A or control foods) and Variety (low or high) revealed a main effect of Food [$F(1, 29) = 34.53$, $p < .001$, $\eta^2_G = 0.31$], Variety [$F(1, 29) = 5.46$, $p < .05$, $\eta^2_G = 0.03$], and a significant interaction effect [$F(1, 29) = 4.52$, $p < .05$, $\eta^2_G = 0.03$]. Post-hoc analysis showed a significant difference in change in desire between food A and the control foods in both meal varieties (LV: $p < .001$; HV: $p < .05$). A two-way ANOVA with Food (B or control) and Variety (low or high) as factors showed a significant main effect of Food on the difference scores of desire [$F(1, 29) = 25.30$, $p < .001$, $\eta^2_G = 0.21$], a significant effect of Variety [$F(1, 29) = 7.90$, $p < .01$, $\eta^2_G = 0.06$], and a significant interaction effect [$F(1, 29) = 7.91$, $p < .01$, $\eta^2_G = 0.05$]. Post-hoc analysis revealed a significant difference between the difference scores for desire for food B and the control foods in the LV session ($p < .001$), but not for the HV session ($p = .41$). The post-hoc analyses for foods A and B further showed that the difference scores for desire for the control foods did not significantly differ between the two meal varieties ($p = 1.00$).

Change in desire for the entire meal was analysed with a two-way repeated measures ANOVA with food (meal or control) and variety (low or high) as factors to explore whether this would follow the same pattern as overall meal SSS. The results showed a main effect of food [$F(1, 29) = 58.98$, $p < .001$, $\eta^2_G = 0.36$], variety [$F(1, 29) = 13.65$, $p < .001$, $\eta^2_G = 0.10$], and a significant interaction effect [$F(1, 29) = 14.90$, $p < .001$, $\eta^2_G = 0.09$]. Post-hoc analysis of the interaction revealed that the difference scores for desire were significantly different between the meal and the control foods for both sessions LV ($p < .001$) and HV ($p < .05$), but it also indicated that the difference scores for desire for the meal were significantly greater in session LV than in session HV ($p < .001$).

Figure 2 depicts the mean change in desire ratings for foods A, B, the overall meal, and the control foods.

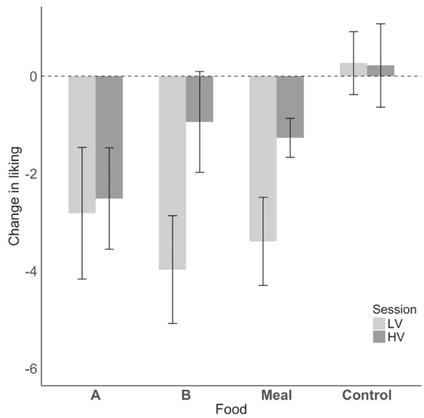

Figure 1. Mean change in liking scores for foods A and B, overall meal and control foods for the LV (low variety) meal and HV (high variety) meal. Error bars represent 95% confidence intervals.

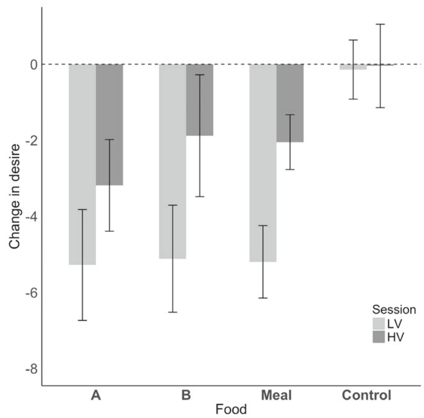

Figure 2. Mean change in desire scores for food A and B, overall meal and control foods for the LV (low variety) meal and HV (high variety) meal. Error bars represent 95% confidence intervals.

Discussion

The present study examined how variety influences the development of SSS for different components of a meal. We hypothesized that level of variety would not affect the development of SSS for a food that participants are equally exposed to, while we did expect it to influence development of SSS when it resulted in less exposure to a food. As expected, strong SSS was present for food A (a cube of cheese) in both sessions thus implying that development of SSS is primarily dependent on the degree of exposure to a food. This suggests that exposure is the mediating factor in the supposed relationship between the variety effect and SSS. Increased variety only results in weaker SSS when it decreases overall orosensory exposure to the food. These study results are in line with the results of earlier studies that demonstrated the importance of orosensory exposure time for the development of satiation (see e.g., Smeets & Westerterp-Plantenga, 2006; Hogenkamp & Schiöth, 2013; Robinson et al., 2014). In our exploratory analysis, we found no difference in change of pleasantness for the control foods between the low and high variety meals, indicating that eating a food to satiety does not necessarily make an uneaten food more palatable.

In the current study, the change in desire to eat the foods followed approximately the same pattern of results as the liking scores. It only deviated from the pattern of results of the liking scores for food A (i.e., change in desire did seem to be influenced by overall meal variety). This suggests that meal variety can directly affect desire (but not liking) for its components. There has been much discussion about the question whether liking and wanting refer to similar aspects of food reward or represent independent constructs (Havermans, 2011; Pool et al., 2016). Due to the fact that in this study no behavioural outcome measures were used, the results of this study do not provide any indication on how liking and wanting inform behaviour. A future study might examine whether participants, after having consumed a fixed amount of a food in either a high variety or low meal variety condition, would be more willing to earn additional servings of that food after having consumed it in the high variety condition, despite (presumably) equal degree of SSS between the two conditions (see Havermans, Janssen et al., 2009).

A limitation of this study is that the ‘meals’ which were presented to the participants are nothing like a meal one would normally enjoy; that is, the foods used in the study were not alien to the participants but the manner in which they were served and had to be consumed (i.e., through signalled exposure) was. The signalled exposure procedure grants considerable control over consumption and sensory exposure (including its timing) on the part of the experimenter, but it is unlikely that the participants experienced this procedure as having an actual meal. Therefore, it is uncertain whether the pattern of results observed in the current study has any external validity. In future studies, a more naturalistic meal could be used. One could serve plated meals containing multiple components with different relative volumes. With equal overall variety, one would then still expect to observe differential SSS for the separate meal components with the largest decrease in liking for the component with the largest volume. A second limitation of the study is the skewed gender-balance in the study population. The study population consisted largely of females. However, a review by Remick et al. (2009) suggests that gender does not affect SSS.

The results of this study tentatively suggest that SSS might not be sensitive to dishabituation (Hetherington & Havermans, 2013). If so, we would have expected to see a direct effect of meal variety on SSS for food A and this was not the case. However, we cannot fully exclude the possibility that in both conditions the exposure to (a) different food(s) in between consumption of (a cube of) cheese dishabituated SSS for the cheese, resulting in weaker SSS for the cheese than would have occurred if participants had not eaten anything in between (a pause). Future studies to further investigate whether SSS can be dishabituated may therefore add a condition in which the alternative/dishabituating food(s) (in this study food B in the low variety meal and BCDEF in the high variety meal) is replaced by eating nothing, to investigate whether it is the exposure to an alternative food that might recover the evaluation of the test food or whether this is due to spontaneous recovery, unaffected by exposure to a different stimulus.

In sum, the present study results show that the development of SSS is primarily determined by the degree of exposure to a food, and thus indicate that exposure mediates the relationship between food variety and SSS. More variety results in less SSS for a food if, and only if it decreases exposure to this food. The results of this study thus provide a useful starting point for investigating how to influence SSS. As the sensory satiation for foods depends on the amount of exposure to the foods, shortening or prolonging this exposure might be a useful strategy to influence the development of SSS and presumably food intake. Next to variety, the texture of a food or eating rate can also impact orosensory exposure time (De Graaf, 2012; Robinson et al., 2014; Hogenkamp & Schiöth, 2013). More research is needed to explore what strategies could be used to influence orosensory exposure time and to investigate its effects on SSS and food intake.

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References

Aguinis, H., Gottfredson, R. K., & Joo, H. (2013). Best-practice recommendations for defining, identifying, and handling outliers. *Organizational Research Methods*, *16*(2), 270–301. http://doi.org/10.1177/1094428112470848

Bakeman, R. (2005). Recommended effect size statistics for repeated measures designs. *Behavior Research Methods*, *37*(3), 379–384.

Brondel, L., Lauraine, G., Van Wymelbeke, V., Romer, M., & Schaal, B. (2009). Alternation between foods within a meal. Influence on satiation and consumption in humans. *Appetite*, *53*(2), 203–209. https://doi.org/10.1016/j.appet.2009.06.009

Brondel, L., Romer, M., Van Wymelbeke, V., Pineau, N., Jiang, T., Hanus, C., & Rigaud, D. (2009). Variety enhances food intake in humans: Role of sensory-specific satiety. *Physiology & Behavior*, *97*(1), 44–51. https://doi.org/10.1016/j.physbeh.2009.01.019

Brunstrom, J. M., & Mitchell, G. L. (2006). Effects of distraction on the development of satiety. *British Journal of Nutrition*, *96*(4), 761–769. https://doi.org/10.1079/BJN20061880

De Graaf, C. (2012). Texture and satiation: The role of oro-sensory exposure time. *Physiology & Behavior*, *107*(4), 496–501. https://doi.org/10.1016/j.physbeh.2012.05.008

Epstein, L. H., Robinson, J. L., Roemmich, J. N., Marusewski, A. L., & Roba, L. G. (2010). What constitutes food variety? Stimulus specificity of food. *Appetite*, *54*(1), 23–29. https://doi.org/10.1016/j.appet.2009.09.001

Faul, F., Erdfelder, E., Lang, A. G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods*, *39*(2), 175–191. https://doi.org/10.3758/BF03193146

Havermans, R. C. (2011). “You Say it’s Liking, I Say it’s Wanting ...”. On the difficulty of disentangling food reward in man. *Appetite*, *57*(1), 286-294. https://doi.org/10.1016/j.appet.2011.05.310

Havermans, R. C., Geschwind, N., Filla, S., Nederkoorn, C., & Jansen, A. (2009). Sensory-specific satiety is unaffected by manipulations of flavour intensity. *Physiology & Behavior*, *97*(3–4), 327–333. https://doi.org/10.1016/j.physbeh.2009.02.030

Havermans, R. C., Hermanns, J., & Jansen, A. (2010). Eating without a nose: Olfactory dysfunction and sensory-specific satiety. *Chemical Senses*, *35*(8), 735-741. https://doi.org/10.1093/chemse/bjq074

Havermans, R. C., Janssen, T., Giesen, J. C. A. H., Roefs, A., & Jansen, A. (2009). Food liking, food wanting, and sensory-specific satiety. *Appetite*, *52*(1), 222-225. https://doi.org/10.1016/j.appet.2008.09.020)

Hetherington, M. M., Foster, R., Newman, T., Anderson, A. S., & Norton, G. (2006). Understanding variety: Tasting different foods delays satiation. *Physiology & Behavior*, *87*(2), 263–271. https://doi.org/10.1016/j.physbeh.2005.10.012

Hetherington, M. M., & Havermans, R. C. (2013). Sensory-specific satiation and satiety: history, current issues, and future trends. In J. Blundell, & F. Bellisle (Eds.), *Satiation, satiety, and the control of food intake* (pp. 253-269). Cambridge: Woodhead Publishing.

Hetherington, M. M., & Rolls, B. J. (1996). Sensory-specific satiety: Theoretical frameworks and central characteristics. In E. D. Capaldi (Ed.), *Why we eat what we eat: The psychology of eating* (pp. 267–290). Washington, DC: American Psychological Association. http://dx.doi.org/10.1037/10291-010

Hogenkamp, P. S., & Schiöth, H. B. (2013). Effect of oral processing behaviour on food intake and satiety. *Trends in Food Science & Technology*, *34*, 67–75. https://doi.org/10.1016/j.tifs.2013.08.010

McCrory, M. A., Burke, A., & Roberts, S. B. (2012). Dietary (sensory) variety and energy balance. *Physiology & Behavior*, *107*(4), 576–583. https://doi.org/10.1016/j.physbeh.2012.06.012

Pliner, P., Polivy, J., Herman, C. P., & Zakalusny, I. (1980). Short-term intake of overweight individuals and normal weight dieters and non-dieters with and without choice among a variety of foods. *Appetite*, *1*(3), 203–213. https://doi.org/10.1016/S0195-6663(80)80029-8

Pool, E., Sennwald, V., Delplanque, S., Brosch, T., & Sander, D. (2016). Measuring wanting and liking from animals to humans: A systematic review. *Neuroscience and Biobehavioral Reviews*, 63, 124–142. https://doi.org/10.1016/j.neubiorev.2016.01.006

Raynor, H. A., & Epstein, L. H. (2001). Dietary variety, energy regulation, and obesity. *Psychological Bulletin*, *127*(3), 325–341. https://doi.org/10.1037/0033-2909.127.3.325

Raynor, H. A., & Osterholt, K. M. (2012). Greater variety of fruit served in a four-course snack increases fruit consumption. *Appetite*, *59*(3), 662–667. https://doi.org/10.1016/j.appet.2012.08.003

Remick, A. K., Polivy, J., & Pliner, P. (2009). Internal and external moderators of the effect of variety on food intake. *Psychological Bulletin*, *135*(3), 434–451. https://doi.org/10.1037/a0015327

Rijksinstituut voor Volksgezondheid en Milieu (RIVM). NEVO online version 2016/5.0, (Bilthoven: RIVM, 2016).

Robinson, E., Almiron-Roig, E., Rutters, F., De Graaf, C., Forde, C. G., Smith, C. T., Nolan, S. J., & Jebb, S. A. (2014). A systematic review and meta-analysis examining the effect of eating rate on energy intake and hunger. *The American Journal of Clinical Nutrition*, *100*(1), 123–151. https://doi.org/10.3945/ajcn.113.081745

Rolls, B. J. (1986). Sensory-specific Satiety. *Nutrition Reviews*, *44*(3), 93–101. https://doi.org/10.1111/j.1753-4887.1986.tb07593.x

Rolls, B. J. (2018). The role of portion size, energy density, and variety in obesity and weight management. In T. A. Wadden & G. A. Bray (Eds.), *Handbook of Obesity Treatment, Second Edition* (pp. 93-104). New York, NY: The Guilford Press.

Rolls, E. T. (1981). Central nervous mechanisms related to feeding and appetite. *British Medical Bulletin*, *37*(2), 131–134.

Rolls, E. T. (2007). Sensory processing in the brain related to the control of food intake. *Proceedings of the Nutrition Society*, *66*(1), 96–112. https://doi.org/10.1017/S0029665107005332

Rolls, B. J., Rolls, E. T., Rowe, E. A., & Sweeney, K. (1981). Sensory specific satiety in man. *Physiology & Behavior*, *27*(1), 137–142. https://doi.org/10.1016/0031-9384(81)90310-3

Rolls, B. J., Rowe, E. A., & Rolls, E. T. (1982). How sensory properties of foods affect human feeding behavior. *Physiology & Behavior*, *29*(3), 409–417. https://doi.org/10.1016/0031-9384(82)90259-1

Rolls, B. J., Rowe, E. A., Rolls, E. T., Kingston, B., Megson, A., & Gunary, R. (1981). Variety in a meal enhances food intake in man. *Physiology & Behavior*, *26*(2), 215–221. https://doi.org/10.1016/0031-9384(81)90014-7

Rolls, B. J., Van Duijvenvoorde, P. M., & Rolls, E. T. (1984). Pleasantness changes and food intake in a varied four-course meal. *Appetite*, *5*(4), 337–348. https://doi.org/10.1016/S0195-6663(84)80006-9

RStudio Team. (2016). RStudio: Integrated Development for R (Version 1.1.383) [Computer Software]. Boston, MA: RStudio, Inc. Available from http://www.rstudio.com/

Smeets, A. J. P. G., & Westerterp-Plantenga, M. S. (2006). Oral exposure and sensory-specific satiety. *Physiology & Behavior*, *89*(2), 281–286. https://doi.org/10.1016/j.physbeh.2006.06.011

3

Sensory-specific satiation, the variety effect and physical context: does change of context during a meal enhance food intake?

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Abstract

Food variety has been shown to increase food intake, and sensory-specific satiation (a relative decrease in pleasantness of a food as it is consumed) has been proposed as the mechanism through which variety increases consumption. The aim of this study was to investigate whether variation of eating context can add to experienced meal variety and hence increase consumption even further. A total of 128 participants were assigned to one of four conditions in which they first ate a specific food item (ad libitum) until satiated, after which they consumed a second course ad libitum of either the same or a different food in either the same context or in a different context. We hypothesized that, compared to eating the same food in the same context during the second course, introducing a different food item or changing the context for the second course increases consumption (of the second course), and changing both food and context enhances food intake to a greater degree than only changing the food or changing the context. Results indicated that food variety (introducing a different food) significantly increased consumption in the second course, but that a context switch did not enhance consumption. These results suggest that there is little reason to believe that sensory-specific satiation is context specific.

Introduction

An extensively studied aspect of eating behaviour is sensory-specific satiation (SSS). SSS refers to a decline in pleasantness derived from a food with its consumption, relative to other unconsumed foods (Rolls, 1986; Rolls, Rolls, et al., 1981). According to this concept, a specific food item becomes less liked during its consumption, whereas there is little change in liking for other unconsumed foods. As the established satiation is food specific, SSS promotes the selection of a variety of foods (Rolls, 1986; Rolls, Rolls, et al., 1981; Hetherington & Havermans, 2013). An important function of SSS then is to promote meal variety (Hetherington & Rolls, 1996). Conversely, meal variety itself is thought to delay SSS (Brondel, Lauraine, et al., 2009), and thus to encourage food intake (Hetherington et al., 2006; Brondel, Romer, et al., 2009). Indeed, meal variety has consistently been shown to increase consumption (Raynor & Osterholt, 2012; Remick et al., 2009; Rolls, Rowe, et al., 1981).

Hetherington et al. (2006) demonstrated in a series of two experiments that asking participants to evaluate a different food item during consumption of a food delayed the expected decline in pleasantness of the consumed food and also led to an increased intake, as opposed to only eating and evaluating the same food item. Brondel, Romer et al. (2009) also demonstrated an attenuation of SSS when a variety of foods was introduced. In their experiment, participants were served fries and brownies with or without condiments (ketchup and whipped cream, respectively). The results of this experiment showed that participants ate more of the fries and brownies with (as opposed to without) condiments, and that this effect was associated with attenuated SSS for the fries and brownies. Reviewing 10 within-subjects design studies, McCrory et al. (2012) found an average increase in food intake (energy or amount) of 22% when a meal was varied as opposed to the availability of just one food item. A recent meta-analysis corroborated these findings, reporting a small to medium effect of variety on intake (Embling et al., 2021). Increased food intake due to food variety is commonly referred to as the 'variety effect' (Rolls, Rowe, et al., 1981).

Remick et al. (2009) reviewed 42 articles focusing on factors (internal and external) that possibly moderate this variety effect. They defined internal moderators as 'individual difference or trait variables (i.e., stable characteristics of the individual) that have been hypothesized to influence the magnitude of the variety effect' (p. 434), and external moderators as 'aspects of the situation, including the food itself, which either enhance or diminish the variety effect' (p. 434). They concluded that (according to the literature) internal factors (e.g., gender, weight and dietary restraint) do not seem to act as moderators of the variety effect, with the possible exception of old age (see also Embling et al., 2021). In contrast, external factors such as particular properties of the food and the persons' perception of the situation do seem to moderate the variety effect.

A particular external factor, which is not mentioned in the review of Remick et al. (2009), is the physical context of a meal. Eating does not take place in a vacuum, and hence it makes sense to presume that the precise context or setting in which one enjoys a meal affects the meal experience. Indeed, several studies have investigated the effect of contextual factors or meal situations on food intake, food choice, and food acceptance (García-Segovia et al., 2015; Meiselman, 2006; Rozin & Tuorila, 1993; Stroebele & De Castro, 2004). Rozin and Tuorila (1993) argued in a review that ‘a full understanding of human reactions to foods must place the moment of choice or ingestion in a rich context of both food and non-food influences’ (p. 18). Stroebele and De Castro (2004) summarized research findings concerning ambient influences on food intake and food choice, and concluded, based on these findings, that ambient factors (e.g., the number of people present, eating locations, lighting, et cetera) can influence food choice and consumption. Physical context has also been investigated as a factor which could influence the development of SSS (Garcia-Burgos et al., 2015). Garcia-Burgos et al. (2015) investigated the impact of physical context on the development of SSS, by assessing SSS for a familiar drink (a herbal tea beverage) in either a school cafeteria or a laboratory. Results of this study showed a lower overall magnitude of olfactory SSS in the cafeteria setting, suggesting that contextual variables can affect SSS.

The literature described above indicates that contextual factors can influence food intake, food acceptance, food choice, and the development of SSS. In the present study we aimed to investigate whether altering the physical context during a meal, by changing (elements of) the context in which a meal is served (e.g., temperature, lighting, odour, sound), acts as a dishabituating stimulus that can consequently lead to an increase in meal intake. This expected context-switch effect is based on the widely held assumption that SSS is a form of habituation (in fact, the terms are often even used interchangeably, see Epstein et al., 2009). Habituation has been defined as response decrement to a repeatedly presented stimulus, which is not the result of sensory adaptation or sensory/motor fatigue. Any stimulus that can be habituated, can also be dishabituated (recovery of responding after it has ceased completely) (Rankin et al., 2009). With regard to SSS, this implies that introducing a dishabituating stimulus after SSS has been established (cessation of food consumption) should restore responding to the food just ingested (i.e., consumption of that food is resumed). Such a dishabituating stimulus can be a food or non-food stimulus (Epstein et al., 2009), including an environmental context.

In order to test for a potential contextual effect as described above, a study design consisting of four experimental conditions was developed. The four conditions differed from each other with regard to food variety and context. Participants first ate a specific food item until satiated (first course), after which they consumed a second course ad libitum of either the same or a different food in either the same context or in a different context. Based on the findings of previous studies and the proposed contextual effect described above, we hypothesized that, compared to eating the same food in the same context during the second course, (1) introducing a different food item would increase consumption in the second course (effectively replicating the ‘variety effect’), (2) changing the context for the second course would increase consumption, and (3) changing both food and context would enhance meal intake to a greater degree than only changing the food or changing the context (synergistic effect). We further expected that SSS would develop for the food consumed in the first course. Note that our expected contextual effect is different from the already investigated effect of external distractions on SSS and consumption (Bellisle & Dalix, 2001; Bellisle et al., 2004; Braude & Stevenson, 2014), since distractors are hypothesized to delay the habituation process, while dishabituation takes place after responding to the stimulus has ceased (Epstein et al., 2009).

Methods

All study procedures were approved by the Maastricht University Ethical Research Committee of Psychology and Neuroscience (reference number: ERCPN-186_04_12_2017) and its proposal was preregistered on The Open Science Framework (https://osf.io/kgdf6).

Study population

To estimate the appropriate number of subjects for the proposed study design, a sample size calculation was performed using G*Power 3.1 (Faul et al., 2007) for a 2 x 2 ANOVA (main effects and interactions), employing an α rejection criterion of 0.05 and 0.80 (1-β) power to detect a medium effect (f = 0.25). There were no prior studies to inform an effect size estimate for our context manipulation, but the size of the food variety effect can be substantial (Embling et al., 2021). Therefore, we considered a medium effect size for the context main effect and an interaction between food variety and a context switch to be relevant and reasonable. To be able to find such an effect, the power calculation indicated a total sample size of 128 participants.

The participants of this study were adult men and women (aged between 18 and 50 years), who were recruited via convenience sampling (e.g., posters and flyers, internet, advertisements, and other related sources). Participants aged above 50 years were excluded due to prior study results suggesting that the variety effect is different for older and younger adults (Remick et al., 2009). Participants were also excluded when they reported adhering to an energy restricting diet. Exclusion criteria further comprised medical or psychological disorders that affected eating (e.g., a history of cancer, gastrointestinal illness, celiac disease, dental surgery within the last three months, COPD, diabetes, or eating disorders) as well as disorders of taste and smell. Participants who indicated to experience difficulties with swallowing/eating, who were hypersensitive or allergic to the food products used in the study or disliked the food items, who were vegan, or pregnant/breastfeeding were also excluded from the study.

Candidate participants were screened before participation in the study to make sure they met the inclusion criteria. They were also informed about the food items included in the study that they were expected to taste and evaluate. In case a participant had a cold (which influenced his/her ability to taste and smell), the scheduled appointment was rescheduled. When included in the study, participants were given the necessary information about participation. The exact nature (i.e., the aim and hypotheses) of the study was not disclosed until after the participant completed his/her participation in the study. Upon completion of the participation, participants were compensated with a €5 gift voucher.

A total of 130 participants participated in the study. Two participants were excluded from the data analysis; one participant was not naïve to the study purpose and the other had difficulties eating the study foods. This resulted in a total of 128 participants (43 male, 85 female), with a mean age of 26.5 (*SD* = 7.2), who were equally distributed over the four study conditions (*N* = 32). Participant characteristics per condition are summarized in Table 1.

Table 1. Participants' characteristics: mean age, mean hunger and thirst, mean intake in course 1, and sex distribution for each condition (Var & Con = food variety and context switch). Values in parentheses represent *SD*.

	Group				
	Control	**Variety**	**Context**	**Var & Con**	
N	32	32	32	32	
Age (years)	26.8 (7.7)	25.2 (6.7)	28.6 (8.4)	25.3 (5.3)	$F(3, 124) = 1.58$, $p = .20$, $\eta_p^2 = 0.04$
Hunger (mm)	50 (24)	50 (23)	52 (18)	48 (21)	$F(3, 123) = 0.25$, $p = .86$, $\eta_p^2 = 0.01$
Thirst (mm)	58 (20)	53 (25)	55 (19)	54 (20)	$F(3, 123) = 0.34$, $p = .80$, $\eta_p^2 = 0.01$
Intake course 1 (g)	41.0 (28.9)	40.3 (31.2)	46.1 (31.5)	32.3 (24.8)	$F(3, 124) = 1.23$, $p = .30$, $\eta_p^2 = 0.03$
Sex	14 men 18 women	10 men 22 women	12 men 20 women	7 men 25 women	$\chi^2 = 3.75$, $p = .29$

Procedure, measurements and design

The participants in the study were tested individually. Each participant took part in an eating session at the laboratory, scheduled between 1 p.m. and 5 p.m. Participants were asked to eat a standard breakfast and/or lunch on the day of the laboratory session and not to eat or drink during the two hours prior to the session (except water, coffee or tea) to ensure that they experienced a certain degree of hunger. Participants were pseudo-randomly assigned to one of four experimental conditions of equal size: Control, Variety, Context, or Var & Con (see Table 2 for the procedure of the experiment). Test foods and laboratory rooms (i.e., contexts) were completely counterbalanced within each of the four conditions. Participants in all conditions had free access to tap water during consumption, and were instructed not to use their phone, read a book, or engage in any other activities that could distract them from the instructed tasks.

Table 2. Experimental design and procedure (Var & Con = food variety and context switch).

	Time →			
Condition		**First course**		**Second course**
Control (*n*=32)	Taste test 1	X[test food A]	Taste test 2	X[test food A]
Variety (*n*=32)				X[test food B]
Context (*n*=32)				Y[test food A]
Var & Con (*n*=32)				Y[test food B]

Note. Both taste tests were completed in the same room (i.e., X) as in which the participant received his/her first course. Further note that 'X' and 'Y' can refer to both laboratory rooms, and 'A' and 'B' can refer to all test foods.

On arrival at the laboratory, the participants were led to one of two laboratory rooms. These rooms had similar size (~11 m^2), but were furnished in a way to create a different sensory experience. The features that differed between both rooms were the positioning of the participant (facing the wall or facing the door), the shape of the bowl in which the food was presented (round or rectangular), the placemat on which the food was placed, the decoration (e.g., plants or paintings), the scent in the room (different varieties of Ambi Pur Electrical house perfumes), and whether the seat of the chair was padded with a (thin) cushion. This was to ensure that the two eating contexts were clearly different from one another in terms of appearance, smell, and even feel, without one room being more distracting (in terms of sensory features) than the other.

3

In all conditions, participants received verbal and written information about the experimental procedure (not the experimental design and hypotheses) and signed an informed consent form. Then, they completed a demographics questionnaire containing questions about age, sex, and educational level (low, middle, or high), and rated their hunger and thirst on a 100-mm visual analogue scale (VAS), ranging from 0 (not at all hungry/thirsty) to 100 (extremely hungry/thirsty). Further, regardless of condition, the participant first tasted and evaluated four savoury foods and four sweet foods, which were matched (approximately) for caloric density, appearance, and texture: salty popcorn (AH zoute popcorn: 510 kcal per 100 g), cucumber (12 kcal per 100 g) and tomato (30 kcal per 100 g) on a stick, tomato juice (Appelsientje Zontomaatje: 18 kcal per 100 g), and grain crisps (Sunbreaks Wavy Grains sea salt flavour: 480 kcal per 100 g); sweet popcorn (AH zoete Popcorn: 425 kcal per 100 g), apple (58 kcal per 100 g) and grape (78 kcal per 100 g) on a stick, fruit juice (Appelsientje Multifruit: 43 kcal per 100 g / Appelsientje Multifruit volle smaak: 25 kcal per 100g), and banana crisps (Smaakt Bananenchips: 504 kcal per 100 g) (National Institute for Public Health and the Environment (RIVM), 2016).

Participants were instructed to evaluate the pleasantness of the eight food items and their desire to eat these food items (taste test 1) by rating 'How much do you like this food right now?' and 'How strong is your desire to eat this food right now?' on 100-mm line scales (VAS) ranging from 0 (not at all) to 100 (extremely). The eight food items (all of them labelled with a three-digit number) were presented by the experimenter to the participant one at a time, together with a sheet containing the corresponding 'pleasantness' and 'desire to eat' scales for the food item, in order to minimize distraction that could be caused by the presence of the other foods. After completion of the taste test, the participant received a large bowl of popcorn (sweet or salty) or crisps (grain or banana) (counterbalanced between participants) and was instructed to "eat until pleasantly full". The food was weighed before and after consumption, and the weights were noted to calculate the amount of food consumed. During this ad libitum consumption, the experimenter was not present. When the participant had finished, wanted to have more of the food or water, or had any questions, he/she could contact the experimenter using a wireless communication system (a radiotelephone). Directly after the ad libitum consumption of the popcorn or crisps the participant was again instructed to taste and evaluate all eight aforementioned food items (taste test 2), which were presented to the participant following the same procedure as the first taste test.

After the second taste test, all participants received a second serving (or course) of either the same test food or a different test food (crisps in case the test food for the first course was popcorn; popcorn if the test food for the first course was crisps; salty when first course was sweet and vice versa) for ad libitum consumption. The food was again weighed before and after consumption. The second course was served in either the same room or a different room. In condition 'Control' (no food variety, no context switch) the participant received the same test food in the second course and stayed in the same room. Condition 'Variety' (food variety, no context switch) is equal to condition 'Control' except that participants in this condition received a different test food in the second course. Participants in condition 'Context' (no food variety, context switch) received the same test food in the second course, but were moved to the other laboratory room. Participants in condition 'Var & Con' (food variety and context switch) received a different test food and were also moved to the other laboratory room. Participants who were moved to a different room were simply told that the second part of the experiment would take place in a different room. None of the participants asked questions about this. During this second course the experimenter was also not present. The participant could contact the experimenter using the radiotelephone when he/she had finished, wanted to have more of the food or water, or had any questions. After the participants had finished the second course they were asked what they thought the study was investigating. For this purpose, participants answered the question: 'What do you think this experiment is about?'. Six of the participants correctly guessed the aim of the study regarding SSS. These participants were included in the analyses since excluding these participants from the analyses did not affect the results.

Data analysis

We checked the equivalence of the four groups in terms of participant age, initially rated hunger and thirst levels, and amount consumed in the first course with separate one-way ANOVAs with Group (Control, Variety, Context, Var & Con) as between-subjects factor. No significant differences between groups were found (see Table 1). We further checked the equivalence of the four groups in terms of sex distribution with a Chi-square test (see Table 1), which also showed no significant differences.

Development of SSS as the result of the first course was analysed by calculating differences between the ratings of pleasantness and desire to eat the food items of taste test 1 and taste test 2 for the test food and the uneaten control foods for all participants. For the uneaten foods, these difference scores were averaged into a single difference score. We used a two-way ANOVA with Group (Control, Variety, Context and Var & Con) and Food (eaten vs. control) as factors to test the development of SSS. Note that the food pleasantness ratings are viewed as the primary outcome variable for determining SSS. We further intended to explore to what degree the expected decrease in pleasantness and desire ratings for the test food generalized to the uneaten foods that shared either textural, visual (i.e., the texture and appearance of the uneaten popcorn or crisps) or taste (either sweet or savoury depending on the taste of the test food consumed) characteristics. These exploratory analyses can be found in our supplemental materials on The Open Science Framework (https://osf.io/54gaf/). The data of two participants were removed for the SSS and 'desire to eat' analyses due to missing values for one of the control foods.

To test the potential effects of food variety and a context switch on consumption, the amount of food eaten in the second course was calculated by averaging the volume (weight) and amount (energy in kcal) of the foods consumed for each condition. Differences between the experimental conditions were then analysed using a 2 (Context: same or different) x 2 (Food: same or different) ANOVA. This ANOVA was the key test for examining the three hypotheses outlined in the Introduction section.

Note that for the analyses to assess SSS (given course 1) and a potential effect on intake due to a context or food switch (given course 2), the relevant data were first screened for error outliers (e.g., due to incorrect data entry), interesting outliers (e.g., unexpected extreme values not due to error), and influential outliers (data points outside a mean ± 3 *SD* range) as recommended by Aguinis et al. (2013). No error outliers were present. Four (potentially) influential outliers were winsorized.

All analyses were performed in R, using the RStudio® software package and the packages 'pastecs', 'ggplot2', 'ez', 'reshape', 'reshape2', 'psych', 'car', 'gmodels', and 'plyr' (RStudio Team, 2016). All effects are reported as significant at $p < .05$. Effect sizes (η_p^2) were calculated using the spreadsheet provided by Lakens (2013). The anonymized raw data and the R scripts used for the analyses are available on The Open Science Framework (https://osf.io/54gaf/).

Results

A two-way mixed ANOVA (group x food) for pleasantness ratings (the primary outcome variable for determining SSS) showed only a significant main effect of food [F(1, 122) = 19.05, p < .0001, $\eta_G^2 = 0.07$]. There was no significant main effect of group [F(3, 122) = 1.20, p = .31, $\eta_p^2 = 0.03$], and no interaction effect [F(3, 122) = 0.84, p = .47, $\eta_G^2 = 0.01$], indicating that SSS was present in each of the conditions. Next to assessing SSS in terms of change in pleasantness, we also tested whether there was a significant change in desire ratings for the consumed foods as compared to the control foods (two-way ANOVA: group x food). This ANOVA showed the same pattern as the ANOVA for pleasantness ratings; only a significant main effect of food [F(1, 122) = 53.18, p < .0001, $\eta_G^2 = 0.16$], indicating that desire ratings to eat the consumed foods dropped significantly more than these ratings for the control foods in all conditions. There was no significant effect of group [F(3, 122) = 0.96, p = .41, $\eta_p^2 = 0.02$], and no interaction [F(3, 122) = 2.01, p = .12, $\eta_G^2 = 0.02$]. See Figure 1 and 2 for mean changes (and 95% confidence intervals) for pleasantness ratings and desire ratings per condition and food (eaten vs. control foods). See the supplemental materials for means and *SD* for pleasantness and desire difference scores per condition for eaten and control foods. See also the supplemental materials for pretest pleasantness and desire ratings for eaten and control foods for each condition separately.

A two-way ANOVA testing the effect of food variety and a context switch on intake in the second course in grams showed only a significant main effect of food variety [F(1, 124) = 11.14, p < .01, $\eta_p^2 = 0.08$], while an effect of context [F(1, 124) = 1.34, p = .25, $\eta_p^2 = 0.01$], and an interaction [F(1, 124) = 0.71, p = .40, $\eta_p^2 = 0.01$] were absent. For intake in kcal in course 2, the two-way ANOVA indicated a similar pattern. Only food variety had a significant effect [F(1, 124) = 10.97, p < .01, $\eta_p^2 = 0.08$] on intake in kcal (no effect of context [F(1, 124) = 1.22, p = .27, $\eta_p^2 = 0.01$], or an interaction [F(1, 124) = 0.75, p = .39, $\eta_p^2 = 0.01$]). Figures 3 and 4 show mean intake (and 95% confidence intervals) in course 2 per condition in grams and kcal, respectively (means and *SD* for intake in grams as well as intake in kcal can be found in the supplemental materials). These results indicate that only food variety enhanced intake in a second course, while a context switch did not have any influence on consumption.[1]

1 Based on a reviewer suggestion we explored whether gender influenced the reported results. A three-way ANOVA (gender x food variety x context) revealed neither a main effect of gender, nor any interaction effects with gender (all p's > .05).

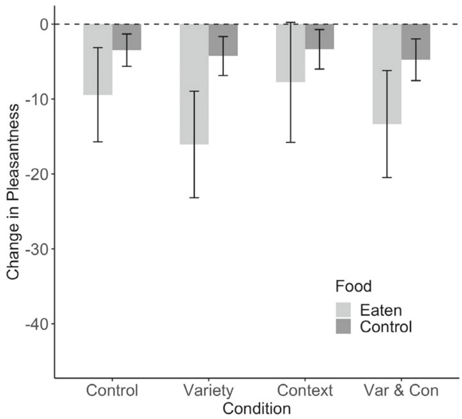

Figure 1. Mean change in pleasantness ratings for all conditions in mm (Var & Con = food variety and context switch). Error bars represent 95% confidence intervals.

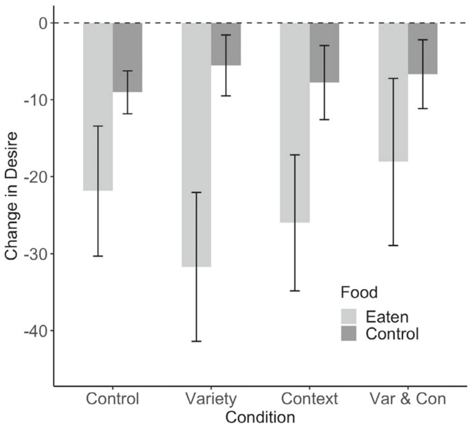

Figure 2. Mean change in desire ratings for all conditions in mm (Var & Con = food variety and context switch). Error bars represent 95% confidence intervals.

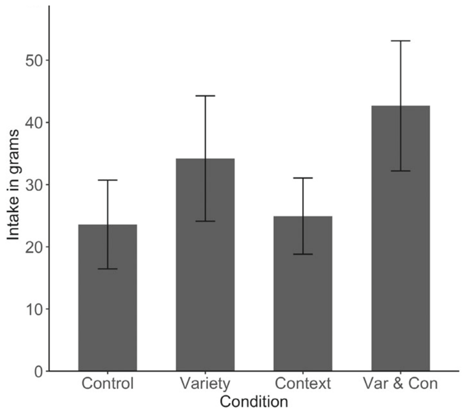

Figure 3. Mean intake per condition in course 2 in grams. Error bars represent 95% confidence intervals. (Var & Con = food variety and context switch)

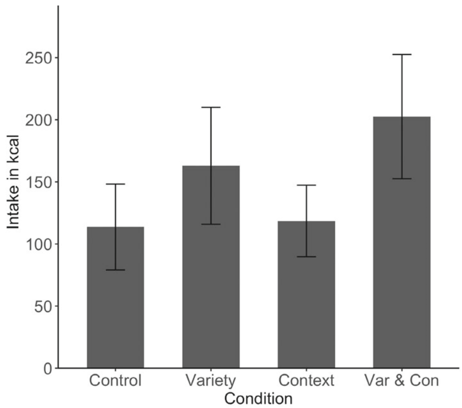

Figure 4. Mean intake per condition in course 2 in kcal. Error bars represent 95% confidence intervals. (Var & Con = food variety and context switch)

Discussion

In this experiment, we investigated SSS and the effect of food variety and a context switch on consumption (the primary aim of the study). The results of this study showed that pleasantness and desire ratings for consumed food items (in course 1) dropped significantly more after consumption than these ratings for control foods, thereby replicating SSS. Furthermore, we replicated the variety effect as our results showed that introducing a different food increased consumption in the second course. We did not find any evidence that a context switch enhances consumption, which implies that SSS is not context-specific. The results indicate that SSS develops specifically for the food that is consumed, and not for the situation in which this food is consumed (i.e., it is a truly sensory 'specific' satiation; see also Higgs et al., 2008). Next to that, if SSS is indeed a form of habituation, implying it is possible to dishabituate SSS, the context switch should have resulted in a recovery of consumption when the same food was presented in a different context. The absence of a dishabituating contextual effect in our study suggests either that SSS is not a form of habituation (see also Hetherington & Havermans, 2013), or that the dishabituating stimulus (i.e., the switch in context) was not salient enough.

The absence of a contextual effect might be due to the relatively subtle context manipulation. The context manipulation in this study was mainly produced by altering certain details in two fairly similar laboratory rooms (e.g., a rug on the floor versus no rug on the floor, or a cushion on the chair versus no cushion on the chair), in order to create equally 'distracting' contexts, without one of these being more or less associated with food consumption (e.g., a dining room). One might argue that these differences may have been too subtle to have been noted by participants, and therefore they did not experience a contextual difference. In this study, we did not check whether participants noticed the differences between the rooms and whether they experienced it as a different 'ambience'. It is not known whether one has to be consciously aware of this 'context switch' for it to have an effect on consumption. However, considering that participants had to actively walk to another room makes it hard to contend that they might have been oblivious to the switch in context itself. Nonetheless, future research should examine whether a stronger (and more discernible) context manipulation does affect food intake, and whether its noticeability is key for its effectiveness. Another limitation of this study is that the 'meal' in this study does not necessarily resemble what is regarded as a typical meal. The foods in the study are not alien to the participants, but the way in which they were presented (in two 'snack' courses) might have been, which affects the external validity of the study results.

In conclusion, this study replicated the effect of food variety on consumption and demonstrated SSS and a relative decrease in desire to consume a food just eaten until pleasantly full. A change in context during the 'meal' did not enhance intake. Since the absent effect of our contextual manipulation on food intake might be due to the subtlety of the manipulation, future research should examine whether a stronger and more noticeable context change could have an effect on consumption.

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References

Aguinis, H., Gottfredson, R. K., & Joo, H. (2013). Best-Practice Recommendations for Defining, Identifying, and Handling Outliers. *Organizational Research Methods*, *16*(2), 270–301. https://doi.org/10.1177/1094428112470848

Bellisle, F., & Dalix, A. M. (2001). Cognitive restraint can be offset by distraction, leading to increased meal intake in women. *American Journal of Clinical Nutrition*, *74*(2), 197–200.

Bellisle, F., Dalix, A. M., & Slama, G. (2004). Non food-related environmental stimuli induce increased meal intake in healthy women: Comparison of television viewing versus listening to a recorded story in laboratory settings. *Appetite*, *43*(2), 175–180. https://doi.org/10.1016/j.appet.2004.04.004

Braude, L., & Stevenson, R. J. (2014). Watching television while eating increases energy intake. Examining the mechanisms in female participants. *Appetite*, *76*, 9–16. https://doi.org/10.1016/j.appet.2014.01.005

Brondel, L., Lauraine, G., Van Wymelbeke, V., Romer, M., & Schaal, B. (2009). Alternation between foods within a meal. Influence on satiation and consumption in humans. *Appetite, 53*(2), 203–209. https://doi.org/10.1016/j.appet.2009.06.009

Brondel, L., Romer, M., Van Wymelbeke, V., Pineau, N., Jiang, T., Hanus, C., & Rigaud, D. (2009). Variety enhances food intake in humans: Role of sensory-specific satiety. *Physiology & Behavior, 97*(1), 44–51. https://doi.org/10.1016/j.physbeh.2009.01.019

Embling, R., Pink, A. E., Gatzemeier, J., Price, M., Lee, M. D., & Wilkinson, L. L. (2021). Effect of food variety on intake of a meal: a systematic review and meta-analysis. *The American Journal of Clinical Nutrition*, *113*(3), 716–741. https://doi.org/10.1093/ajcn/nqaa352

Epstein, L. H., Temple, J. L., Roemmich, J. N., & Bouton, M. E. (2009). Habituation as a determinant of human food intake. *Psychological Review*, *116*(2), 384–407. https://doi.org/10.1037/a0015074

Faul, F., Erdfelder, E., Lang, A-G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods*, *39*(2), 175–191. https://doi.org/10.3758/BF03193146

Garcia-Burgos, D., Secchiari, F., & Calviño, A. (2015). Is sensory-specific satiety for a bitter-sweet infusion modulated by context? *Physiology & Behavior*, *140*, 180–187. https://doi.org/10.1016/j.physbeh.2014.12.035

García-Segovia, P., Harrington, R. J., & Seo, H-S. (2015). Influences of table setting and eating location on food acceptance and intake. *Food Quality and Preference*, *39*, 1–7. https://doi.org/10.1016/j.foodqual.2014.06.004

Hetherington, M. M., Foster, R., Newman, T., Anderson, A. S., & Norton, G. (2006). Understanding variety: Tasting different foods delays satiation. *Physiology & Behavior, 87*(2), 263–271. https://doi.org/10.1016/j.physbeh.2005.10.012

Hetherington, M., & Havermans, R. C. (2013). Sensory-specific satiation and satiety. In J. E. Blundell & F. Bellisle (Eds.), *Satiation, satiety and the control of food intake. Theory and practice* (pp. 253–269). Cambridge: Woodhead Publishing Ltd. https://doi.org/10.1533/9780857098719.4.253

Hetherington, M. M., & Rolls, B. J. (1996). Sensory-specific satiety: Theoretical frameworks and central characteristics. In E. D. Capaldi (Ed.). *Why we eat what we eat: The psychology of eating* (pp. 267–290). Washington, DC: American Psychological Association. https://doi.org/10.1037/10291-010

Higgs, S., Williamson, A. C., Rotshtein, P., & Humphreys, G. W. (2008). Sensory-specific satiety is intact in amnesics who eat multiple meals. *Psychological Science*, *19*(7), 623–628. https://doi.org/10.1111/j.1467-9280.2008.02132.x

Lakens, D. (2013). Calculating and reporting effect sizes to facilitate cumulative science: a practical primer for t-tests and ANOVAs. *Frontiers in Psychology*, *4*, 863. https://doi.org/10.3389/fpsyg.2013.00863

McCrory, M. A., Burke, A., & Roberts, S. B. (2012). Dietary (sensory) variety and energy balance. *Physiology & Behavior, 107*(4), 576–583. https://doi.org/10.1016/j.physbeh.2012.06.012

Meiselman, H. L. (2006). The role of context in food choice, food acceptance and food consumption. In R. Shepherd & M. Raats (Eds.), *The Psychology of Food Choice* (pp. 179–199). Wallingford: CABI. https://doi.org/10.1079/9780851990323.0179

National Institute for Public Health and the Environment (RIVM) (n.d.). NEVO online version 2016/5.0, (Bilthoven: RIVM, 2016).

Rankin, C. H., Abrams, T., Barry, R. J., Bhatnagar, S., Clayton, D. F., Colombo, J., … Thompson, R. F. (2009). Habituation revisited: An updated and revised description of the behavioral characteristics of habituation. *Neurobiology of Learning and Memory*, *92*(2), 135–138. https://doi.org/10.1016/j.nlm.2008.09.012

Raynor, H. A., & Osterholt, K. M. (2012). Greater variety of fruit served in a four-course snack increases fruit consumption. *Appetite*, *59*(3), 662–667. https://doi.org/10.1016/j.appet.2012.08.003

Remick, A. K., Polivy, J., & Pliner, P. (2009). Internal and external moderators of the effect of variety on food intake. *Psychological Bulletin, 135*(3), 434–451. https://doi.org/10.1037/a0015327

Rolls, B. J. (1986). Sensory-specific Satiety. *Nutrition Reviews*, *44*(3), 93–101. https://doi.org/10.1111/j.1753-4887.1986.tb07593.x

Rolls, B. J., Rolls, E. T., Rowe, E. A., & Sweeney, K. (1981). Sensory specific satiety in man. *Physiology & Behavior*, *27*(1), 137–142. https://doi.org/10.1016/0031-9384(81)90310-3

Rolls, B. J., Rowe, E. A., Rolls, E. T., Kingston, B., Megson, A., & Gunary, R. (1981). Variety in a meal enhances food intake in man. *Physiology & Behavior, 26*(2), 215–221. https://doi.org/10.1016/0031-9384(81)90014-7

Rozin, P., & Tuorila, H. (1993). Simultaneous and temporal contextual influences on food acceptance. *Food Quality and Preference*, *4*(1–2), 11–20. https://doi.org/10.1016/0950-3293(93)90309-T

R Studio Team. (2016). RStudio: Integrated Development for R (Version 1.1.383) [Computer Software]. Boston, MA: RStudio, Inc. Available from http://www.rstudio.com/.

Stroebele, N., & De Castro, J. M. (2004). Effect of ambience on food intake and food choice. *Nutrition*, *20*(9), 821–838. https://doi.org/10.1016/j.nut.2004.05.012

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Do labels indicating the satiating power of a food influence intake and sensory-specific satiation?

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Abstract

Although several studies have investigated the influence of nutrition labelling on food intake, the effect of labels indicating a food's satiating power on food intake and sensory-specific satiation (SSS) is poorly understood. We investigated whether providing information about the satiating power of a meal affects intake and SSS. Participants (19 men and 18 women) consumed the same test meal of pasta salad ad libitum on two occasions, once described as 'light' and once as 'filling'. SSS was determined as the change in liking of the flavour and desire to eat the test meal before and after consumption, compared to seven uneaten foods. As hypothesized, intake increased with a mean (±*SD*) of 31 ± 59 grams and 42 ± 81 kcal when the meal was labelled 'light' as opposed to 'filling' ($p < 0.01$). Ratings for both liking and desire to eat the test meal decreased significantly more after eating than for the control foods ($p < 0.001$), demonstrating SSS. These relative changes in liking and desire to eat did not differ between the label conditions, despite differences in intake. Furthermore, accounting for amount consumed, the magnitude of SSS did not differ between the label conditions. Therefore, the effects of satiation labelling on intake are likely at most only partially mediated by SSS. This study shows that labels indicating the satiating power of a meal can affect intake, warranting caution in the use of such labels on products intended to reduce intake.

Introduction

Food labelling has received much attention in the past decades, with many studies investigating the effects of nutrition labelling (e.g., energy or fat-content) on food intake. These studies have reported mixed findings (see e.g., Bowen et al., 2003; Roefs & Jansen, 2004; Brown et al., 2018; Oostenbach et al., 2019). For example, McCann et al. (2013) found that fat/energy content labelling affected intake of a lunch meal, while Ebneter et al. (2013) failed to find an effect of providing information about fat and energy content on intake of M&M's in undergraduate women. As nutritional knowledge might not be as ubiquitous as presumed (see e.g., Andrews et al., 2009; Breck et al., 2014), nutrition labels might not necessarily affect participant's beliefs about the food and, hence, intake. The effect of food labels denoting the satiating properties of a food have been less studied (see e.g., Yeomans, 2015; Chambers et al., 2015). Such labels could affect food intake, since expected satiation has been found to influence appetite ratings and food intake (see e.g., Forde et al., 2015; Brunstrom, 2014; Wilkinson et al., 2012; but see Guillocheau et al., 2018). Therefore, this study aimed to investigate whether labelling a meal as 'filling' or 'light' could affect beliefs about satiation and thereby affect intake of that meal. Additionally, we explored the effects of such labelling on the magnitude of sensory-specific satiation (SSS, commonly called sensory-specific satiety, is a relative decline in pleasantness of a food during consumption; Rolls et al., 1981) experienced after eating the meal, as this mechanism might mediate the effect of labels on intake.

SSS has been shown to play a role in eating cessation and the consumption of a varied diet (Rolls, 2018). Indeed, presenting a different food after consumption of a specific food leads to greater intake as compared to presenting the same food item again (Rolls et al., 1981). SSS is a basic mechanism (relying on sensory exposure) that has been demonstrated even in individuals with amnesia (Higgs et al., 2008), suggesting that it does not depend on cognitive processing. However, the fact that SSS can occur in the absence of memory of the eating episode does not necessarily mean that it is insensitive to cognitive cues such as food labelling. Results of a study by Rolls et al. (1992) suggest that SSS may be influenced by cognitive processes. In that study, participants with anorexia nervosa with bulimic features and participants with bulimia nervosa were given either a high-energy salad or a low-energy salad as a preload, or no preload, after which they consumed a self-selected lunch. The participants with anorexia nervosa only showed SSS (measured by desire to eat) after consumption of the high-energy salad. In comparison, the participants with bulimia nervosa only demonstrated SSS after consumption of the low-energy salad. Thus, SSS appeared to be influenced by perceptions based on food properties (i.e., energy content) which differed by eating disorder psychopathology. It remains unclear whether cognitive factors related to food properties (e.g., beliefs concerning taste intensity, texture, or satiating capacity) could influence SSS in individuals without a diagnosed eating disorder. Miller et al. (2000) failed to find an effect of nutrition information (fat and energy content) on SSS for potato crisps in healthy subjects, but the effect of information about the satiating value of a food on SSS has not been studied yet.

Here, we aimed to investigate whether labels indicating the satiating power of a food can influence food intake and SSS. Participants were led to believe that they would consume two similar meals with different satiating capacities: a 'light' and a 'filling' meal. We hypothesized that meal intake would increase when the meal was presented as less satiating ('light') compared to more satiating ('filling'). We additionally hypothesized that the cognitive effects of the satiation labels would influence SSS. Since SSS is an important factor in meal termination, we expected that participants would experience a similar relative decline in pleasantness for both meal varieties, despite differences in ad libitum intake. In other words, we expected participants to be able to consume a greater amount of food for a similar hedonic change when the meal was labelled as 'light'. The results of this study provide novel insights into the effects of satiation labels on food consumption and satiation.

Methods

All study procedures were approved by the Ethics Review Committee Inner City faculties (ERCIC) of Maastricht University (ERCIC_164_10_12_2019) and the hypotheses were preregistered on The Open Science Framework (OSF) (https://osf.io/n9a3p). Supplemental materials of the study can be found on OSF (https://osf.io/rf5vu/).

Design

In a randomized crossover design with repeated measures, participants attended two laboratory sessions during which they were asked to consume a pasta salad as lunch (ad libitum). The sessions were separated by a washout period of at least two weeks and were scheduled during typical lunch hours (between 11:00 am and 2:30 pm). In each session the pasta salad was labelled as either a 'light' or a 'filling' meal. The label was intended to influence participant's beliefs about the satiating power of the meal. The order of the label conditions was counterbalanced across the sessions. Intake of the pasta salad was measured by subtracting the post-meal weight (leftovers) from the served weight.

To measure the magnitude of SSS, participants evaluated the pasta salad and seven control foods before and after eating the pasta salad. Participants indicated their liking of the flavour of the foods and their desire to eat the foods, from this point referred to as 'liking' and 'desire to eat'. Pre-meal liking and desire to eat ratings were subtracted from post-meal ratings for the eaten food (pasta salad) and for the control foods, resulting in change scores for both the pasta salad and each control food. A mean change score for the control foods was calculated, which was then compared to the change score for the pasta salad (determining SSS).

Participants

To estimate the minimum number of participants needed in the study, a sample size calculation was performed using G*Power 3.1 (Faul et al., 2007) for a one-tailed dependent samples t-test, using an α rejection criterion of 0.05 and 0.80 (1-β) power to detect a medium effect ($d_z = 0.5$). This calculation indicated a minimum required sample size of 27 participants. We managed to recruit and test 37 participants.

Participants in this experiment were recruited via convenience sampling (e.g., posters and advertisements). The study was presented as a taste test in which we were investigating two pasta salads. Adult men and women aged between 18 and 65 years old were eligible for participation. The age limit of 65 years was chosen due to study results indicating that the sense of taste declines with age (Methven et al., 2012), and that SSS is not as pronounced in older adults as in younger adults (Rolls & McDermott, 1991). Participants were not eligible for the study if they: were currently adhering to a weight-loss or weight-gain diet, had physical or mental health conditions that might affect eating behaviour (e.g., a history of cancer, gastrointestinal illness, celiac disease, dental surgery within the last three months, COPD, diabetes, and eating disorders), chemosensory dysfunction, difficulties with swallowing/eating, hypersensitivity or allergies to the food products used in the study or dislike of the food items, were vegan, or were pregnant or breastfeeding.

Participants were screened prior to enrolment to ensure they met the inclusion criteria. Prior to the screening, participants were informed about the procedure of the experiment and indicated consent. Participants who were eligible were given further information about the procedure of the study and food items they would be expected to consume, but they were not informed of the aim or hypotheses of the study until after data collection was completed. Table 1 displays participant characteristics for the entire sample and for males and females separately.

Table 1. Participant characteristics.

	Men (*N* = 19)		**Women (*N* = 18)**		**Total (*N* = 37)**	
	Mean (*SD*)	**Range**	**Mean (*SD*)**	**Range**	**Mean (*SD*)**	**Range**
Age (years)	44 (13.4)	19 - 64	35.3 (12.4)	18 - 55	39.7 (13.5)	18 - 64
BMI (kg/m2)	26.2 (5.2)	19.6 - 40	23.8 (3.4)	18.3 - 32	25 (4.5)	18.3 - 40
Health concern[a]	83 (14)	59 -100	84 (13)	60 -100	83 (13)	59 - 100
Restraint score[b]	2.5 (0.7)	1.6 - 4.2	2.5 (0.6)	1.7 - 3.6	2.5 (0.6)	1.6 - 4.2

[a] Score on visual analogue scale ranging from 0-100.
[b] Dutch Eating Behavior Questionnaire (van Strien et al., 1986). Range of possible values: 1 - 5.

Foods

The test meal (pasta salad, served at room temperature) consisted of (cooked) mini penne, pesto, snack tomatoes, oregano, and basil. Table 2 provides the approximate weights and corresponding macronutrient content of the test meal (pasta salad) recipe prepared for one participant. The control foods used in the SSS tests were: grape, raw carrot, grain crisp, sweet popcorn, fruit yogurt, chocolate chip cookie, and Tuc (salty cracker) (see supplemental Table S1). These control foods were chosen based on their distinct sensory and nutritional properties. See supplemental Table S1 for nutritional content of the control foods per 100 grams, and supplemental Table S2 for weight and energy content of each sample provided in the SSS test. The total approximate weight and kcal of the food samples consumed in each SSS test was 30.3 grams and 58 kcal, respectively.

Table 2. Nutritional content (kcal, fat, carbohydrate, and protein) of the test meal (pasta salad) recipe, prepared for one participant.

Test meal recipe for 1 participant (728 g)	Kcal	Fat (g)	CHO (g)	Protein (g)
200 g (raw) mini penne ≈ 500g cooked (Grand'Italia Mini penne tradizionali)	706	2.6	142	26
167 g snack tomatoes (AH Snoepgroente tomaat)	51.8	1.3	6.7	1.5
60 g pesto (Grand'Italia Pesto Rosso)	230.4	21.6	5	3.5
0.5 g oregano[a] (Verstegen oregano)	1.8	0.1	0.2	0.1
0.5 g basil[a] (Verstegen basilicum)	1.2	0	0.1	0.1
Nutritional values test meal recipe	991.2	25.6	154	31.2
Nutritional values test meal per 100g	136.2	3.5	21.2	4.3

[a] Nutritional values derived from the Dutch Food Composition Table (NEVO-online, version 2019/6.0).

Procedure

Participants were instructed to eat breakfast as usual and not to eat (or drink energy-containing beverages) during the three hours prior to their scheduled laboratory session. At the start of both sessions, participants were instructed to read an information sheet informing them of the meal they would consume during that session (either the light or filling version of the test meal). This information sheet remained present on the participant's table during the entire session. Participants were requested not to engage in any activities that could distract them from the instructed tasks, such as using their phone or reading a book. After having read the information sheet, participants were asked at what time they last ate to check whether they adhered to the instructions. Next, participants tasted and evaluated a sample of the test meal (presented with the label of that session) and the seven control foods (SSS pre-test). They were instructed to taste the food items one by one and rate how much they liked the flavour of the food (liking; 'How pleasant do you find the flavour of this food right now?'), and their desire to eat the food (desire to eat; 'How strong is your desire to eat this food right now?'), on a visual analogue scale (VAS) ranging from 0 (not at all) to 100 (extremely). Participants received 100 ml of water to rinse their mouth in between the tastings if they wanted to. After this SSS pre-test, participants indicated how hungry and full they felt at that moment on a VAS ranging from 0-100 (not at all hungry/full - extremely hungry/full).

Next, they received a plate with 500 grams of the test meal (pasta salad) version corresponding to the assigned condition for that session and a glass of water (approximately 325 grams), which were both covertly weighed before providing them to the participant to the nearest 0.1 g (scale: KERN model 440-49N). Participants were told they could eat and drink as much as they would like and were asked to use a radiotelephone to notify the researcher when they had finished. If participants finished the entire meal, they were offered a second serving. Only one participant consumed a second serving (due to an error, on three occasions, participants were not offered more food after clearing the plate). Meal and water leftovers were weighed covertly to determine meal and water intake.

After participants finished eating they were asked to evaluate the meal by answering the following questions: 'How filling did you find this pasta salad?' (VAS ranging from 0 [not at all filling] to 100 [extremely filling]), 'How healthy do you think this pasta salad is?' (VAS ranging from 0 [not at all healthy] to 100 [extremely healthy]), 'How many calories (kcal) do you think you consumed?', and 'How many calories (kcal) do you think this meal contains per 100 grams?'. The participants also indicated post-meal hunger and fullness using a VAS, before tasting and rating the eight food samples again for the SSS post-test. The procedures of both SSS tests were identical.

At the end of the second session, participants completed a questionnaire to assess demographic and eating behaviour characteristics including age, sex, health concerns ('How important is your health for you?', VAS ranging from 0 [not at all important] to 100 [extremely important]), and the restraint scale of the Dutch Eating Behavior Questionnaire (DEBQ; van Strien et al., 1986). The participants were also asked to indicate whether they noticed any differences between the meals (and if yes, what they noticed), whether they preferred any of the meals (and if yes, which one), how they thought the meals were different, and what they thought we were investigating in the experiment. After completing this questionnaire, participants' height and weight were measured to calculate their BMI (body mass index). Lastly, participants were compensated for their participation with a €10 gift voucher.

Statistical analysis

All analyses were performed in R using the RStudio® software package (RStudio Team, 2021) and the packages 'reshape', 'reshape2', 'ggplot2', 'ggpubr', 'plyr', 'dplyr', 'pastecs', 'psych', 'ez', 'gmodels', and 'nlme'. Effect sizes (Cohen's d_z, η^2_G, and η^2_p) were calculated using the spreadsheet provided by Lakens (2013). The anonymized data and R scripts are available on OSF (https://osf.io/rf5vu/). The data for the main (intake and SSS) analyses were first screened for error outliers (e.g., due to potentially incorrect data entry), interesting outliers (e.g., unexpected extreme values not due to error), and influential outliers (Aguinis et al., 2013). Influential outliers (outside mean +/- 3 *SD* range) were winsorized (clipping the outlier to match the value of the next highest or lowest data point).

To test the hypothesized effect of the satiation information (label) on consumption (weight and energy), the amount of food eaten was calculated by subtracting the post-meal weight (leftovers) from the initial weight of the test meal. Differences between the experimental conditions were then analysed using a one-tailed dependent samples t-test ('light meal' vs 'filling meal'). We explored whether the order of the sessions or participant sex influenced these results with mixed design ANOVA's. Furthermore, the influence of BMI, health concerns, and restraint was explored with multilevel linear models. The effect of the label (denoting satiating power) on SSS (both in terms of liking and desire to eat) was analysed using a three-way repeated measures ANOVA with label ('light' vs. 'filling'), food (eaten vs. control foods), and timepoint (pre- vs. post-meal) as factors. Liking and desire to eat ratings were incorporated as dependent variable.

We used two-tailed dependent samples t-tests to explore whether there were any perceived differences between the meals in caloric content (per 100 g), calories consumed, and healthiness. Further, we explored whether there were any differences in change in hunger and fullness between the meals with two-tailed dependent samples t-tests. Changes in hunger and fullness were calculated by subtracting the pre-meal ratings from the post-meal ratings. Lastly, we explored whether participants noticed any differences between the meals, how they thought the meals were altered, and whether they preferred any of the meals. Results are considered significant at $p < 0.05$. Performing all main (intake and SSS) analyses without participants who were aware of the study rationale ($N = 9$), smokers ($N = 2$) or plate clearers ($N = 7$ for the filling meal and $N = 11$ for the light meal) did not alter the findings, therefore results of the entire sample are reported.

Results

Test meal intake

Participants consumed a greater weight of food ($M^{light} = 344.6$, $SD^{light} = 144.4$, $M^{filling} = 313.5$, $SD^{filling} = 126.6$) and more energy ($M^{light} = 469.3$, $SD^{light} = 196.6$, $M^{filling} = 427$, $SD^{filling} = 172.4$) when presented with the 'light' compared to the 'filling' pasta salad ($t_{(36)} = -3.18$, $p < 0.01$, Cohen's $d_z = 0.51$) (Figure 1). Several participants consumed the entire 500 grams of pasta they received and one participant consumed an additional serving. These participants are considered plate clearers ($N = 7$ for the filling meal and $N = 11$ for the light meal). Results were similar when the plate clearers were removed from the analyses ($t_{(25)} = -2.02$, $p < 0.05$, Cohen's $d_z = 0.40$).

We explored whether the order of the sessions or individual differences influenced the effect of the labels on intake. The order of the sessions did not have an influence on the results (both grams and kcal) (main effect session order: $F_{(1, 35)} = 0.003$, $p = 0.96$; interaction: $F_{(1, 35)} = 0.81$, $p = 0.37$). There was a main effect of sex on intake ($F_{(1, 35)} = 6.41$, $p < 0.05$, $\eta^2_p = 0.15$), but no interaction between sex and label ($F_{(1, 35)} = 2.92$, $p = 0.10$). Males consumed more than females in both label conditions (see supplemental Figure S1 for intake by sex). We did not find significant main effects of BMI, restraint, or health concerns on intake, nor did they interact with the labels to influence intake (all *p*s > 0.05).

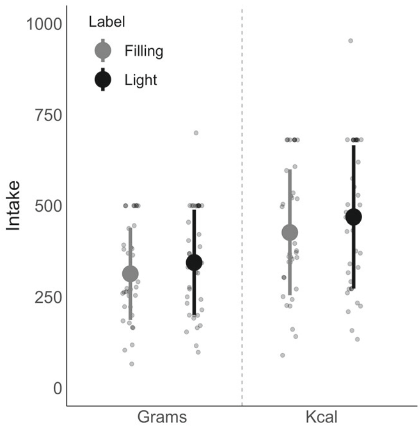

Figure 1. Intake of the pasta salad in both grams and kcal. Mean ± 1*SD*. Small dots represent individual participants. Intake was significantly increased with the ‘light’ label ($p < 0.01$).

Sensory-specific satiation

The three-way ANOVA (food x timepoint x label) showed significant main effects and an interaction of food (pasta salad vs. control foods) and timepoint (pre- vs. post-meal) on liking ratings (main effect food: $F_{(1, 36)} = 57.85$, $p < 0.001$, $\eta^2_G = 0.24$; main effect timepoint: $F_{(1, 36)} = 56.30$, $p < 0.001$, $\eta^2_G = 0.14$; food x timepoint interaction: $F_{(1, 36)} = 32.49$, $p < 0.001$, $\eta^2_G = 0.07$). No main effect of label, a food x label, label x timepoint, or three-way interaction was present (all *p*s > 0.05). Figure 2 shows that the decrease in liking was mainly specific to the test meal (pasta salad), signifying SSS. A post-hoc (one-tailed) dependent samples t-test was conducted on change scores for liking ratings of the pasta salad and control foods (data collapsed across label conditions), which showed that liking ratings declined significantly more for the pasta salad (*M* = -21, *SD* = 18) than for the control foods (*M* = -4, *SD* = 6), $t_{(36)} = -5.83$, $p < 0.001$, Cohen’s $d_z = -0.96$.

Repeating the three-way ANOVA for the desire to eat ratings (which also indicate SSS) showed the same pattern; that is, a significant main effect of food ($F_{(1, 36)} = 38.32$, $p < 0.001$, $\eta^2_G = 0.19$) and timepoint ($F_{(1, 36)} = 170.37$, $p < 0.001$, $\eta^2_G = 0.48$), and a significant food x timepoint interaction ($F_{(1, 36)} = 113.83$, $p < 0.001$, $\eta^2_G = 0.20$). No other

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effects were found (all *p*s > 0.05). The desire to eat ratings declined significantly more for the pasta salad than for the control foods ($M^{pasta} = -46$, $SD^{pasta} = 20$, $M^{control} = -15$, $SD^{control} = 14$, $t_{(36)} = -10.26$, $p < 0.001$, Cohen's $d_z = -1.69$). See Figure 3 for desire to eat ratings of the pasta salad and control foods.

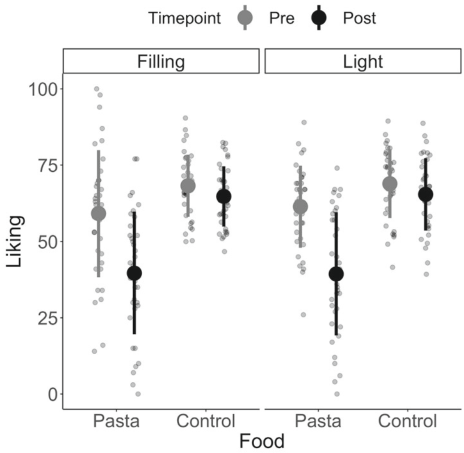

Figure 2. Liking ratings for pasta salad and control foods, pre-meal and post-meal, separated by label condition. Mean ± 1*SD*. Small dots represent individual participants.

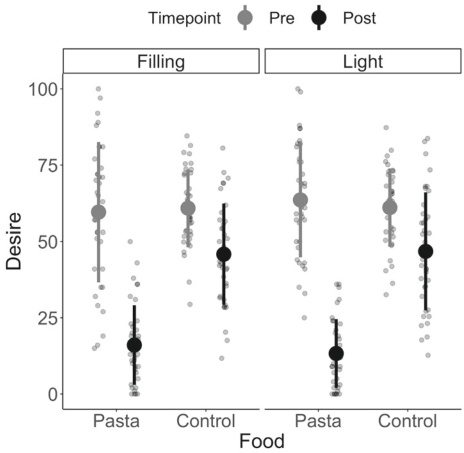

Figure 3. Desire to eat ratings for pasta salad and control foods, pre-meal and post-meal, separated by label condition. Mean ± 1*SD*. Small dots represent individual participants.

Presenting the pasta salad as 'light' promoted greater food intake compared to the 'filling' meal, for a similar magnitude of SSS (decline in ratings of liking and desire to eat the pasta salad relative to the control foods). This suggests that the labels affected the magnitude of SSS, since equal SSS was reached in both label conditions, while intake of the pasta salad was significantly increased when accompanied by the 'light' label.

Exploratory analysis

We explored (not preregistered) the effect of the labels on SSS per grams eaten to investigate whether the labels affected the development of SSS. In this analysis we compared the change in liking and desire to eat the pasta salad and the (mean of the) seven control foods divided by the grams of food ingested (i.e., a change score corrected for grams of food ingested) between the label conditions. A two-way repeated measures ANOVA including food (pasta vs. control foods) and label (filling vs. light) as factors and liking as dependent variable showed only a significant main effect of food (main effect food: $F_{(1, 36)} = 26.46$, $p < 0.001$, $\eta^2_G = 0.17$; main effect label: $F_{(1, 36)} = 0.36$, $p = 0.55$; interaction: $F_{(1, 36)} = 0.73$, $p = 0.40$). Thus, SSS per gram (in terms of liking) did not differ significantly between the labels. For the change in desire to eat the pasta salad as opposed to the control foods, repeating the two-way ANOVA, this time with ‘desire to eat’ as dependent variable, also revealed only a main effect of food (main effect food: $F_{(1, 36)}$ = 81.15, p < 0.001, η^2_G = 0.31; main effect label: $F_{(1, 36)}$ = 0.42, p = 0.52; interaction: $F_{(1, 36)}$ = 2.39, p = 0.13). The change in liking and desire to eat per gram of food eaten was stronger for the pasta salad than for the control foods, but was not affected significantly by the labels. See Figure 4 for change scores per gram both for liking and desire to eat, separated by label.

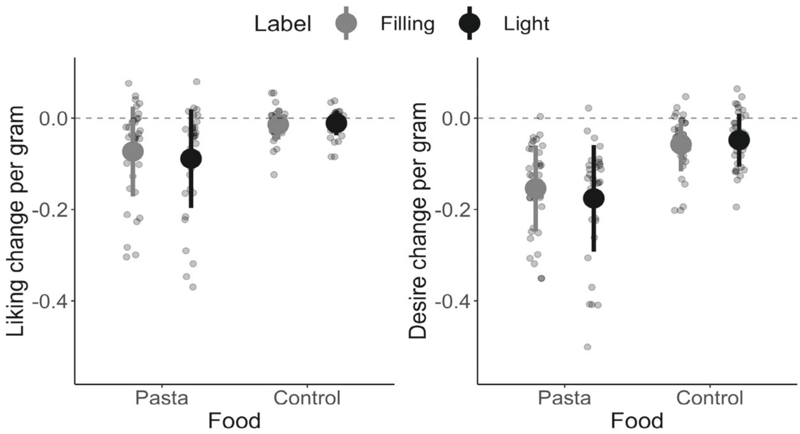

Figure 4. Change score liking (left panel) and desire to eat (right panel) for pasta salad and control foods per gram of food eaten, separated by label (mean ± 1*SD*). Small dots represent individual participants. Liking and desire to eat changes (per gram) did not significantly differ between the label conditions.

Secondary analyses and manipulation check

To check possible influences on the main results of pre-meal hunger and fullness, water consumption during the meal, and pre-test liking and desire to eat ratings of the test meal, we conducted separate dependent samples t-tests comparing the label conditions. No differences were found in pre-meal hunger ratings ($t_{(36)}$ = 1.16, p = 0.25), pre-meal fullness ratings ($t_{(36)}$ = -0.11, p = 0.91) (see Table 3 for means and *SD*s), and in water consumption during the meal between the label conditions (M^{light} = 144.1, SD^{light} = 105.6, $M^{filling}$ = 131.2, $SD^{filling}$ = 90.6, $t_{(36)}$ = -0.99, p = 0.33). There were also no differences between pre-test liking ($t_{(36)}$ = -0.66, p = 0.51), and desire to eat ($t_{(36)}$ = -1.13, p = 0.27) ratings of the filling and light pasta salad (see supplemental Tables S3 and S4 for means and *SD*s). To get some sense of the effectiveness of our manipulation in influencing beliefs about the satiating power of the meal we compared scores for the question ‘How filling did you find this pasta salad?’ with a one-tailed dependent samples t-test. We found that, despite eating more of the ‘light’ labelled pasta salad, participants rated the ’light’ pasta salad (M = 60, SD = 18.1) as less filling than the ‘filling’ pasta salad

($M = 72.3$, $SD = 17.3$), $t_{(36)} = -2.85$, $p < 0.01$), which suggests that our label manipulation effectively influenced participants' beliefs.

Table 3. Means and standard deviations (in parentheses) for pre-meal and post-meal hunger and fullness (VAS 0-100) per session (label 'light' and label 'filling').

	Light		Filling	
	Pre-meal	**Post-meal**	**Pre-meal**	**Post-meal**
Hunger	75 (15)	22 (17)	73 (15)	20 (15)
Fullness	24 (19)	69 (15)	25 (19)	79 (13)

Exploratory analyses

Participants did not estimate the energy density to be different between the light ($M = 173.4$, $SD = 101.3$) and filling ($M = 179.4$, $SD = 118.4$) pasta salad ($t_{(36)} = 0.41$, $p = 0.68$). The estimated calories consumed of the light ($M = 512.2$, $SD = 389.3$) and filling ($M = 483.4$, $SD = 262.9$) pasta salads did also not differ ($t_{(36)} = -0.66$, $p = 0.51$). Several participants indicated, however, that they found it extremely difficult to estimate the energy density of a meal. Analysis of the participants' answers on the question 'How healthy do you think this pasta salad is?' showed that the light and filling pasta salad were perceived as equally healthy ($M^{light} = 55.5$, $SD^{light} = 22.4$, $M^{filling} = 52$, $SD^{filling} = 19.8$), $t_{(36)} = 1.61$, $p = 0.12$.

The analysis of changes in hunger and fullness from pre- to post-meal showed that no differences were present in decline in hunger ($t_{(36)} = 0.05$, $p = 0.96$), and increase in fullness ($t_{(36)} = -1.77$, $p = 0.09$), between the label conditions. When plate clearers were removed from the sample, a significant difference in change in fullness was present ($t_{(25)} = -2.12$, $p = 0.04$); fullness increased significantly more after consumption of the 'filling' pasta salad opposed to the 'light' pasta salad. In other words, without the plate clearers, fullness increased more at the 'filling' meal while less was eaten.

Lastly, we analysed participants' perceived differences between the pasta salads. Half of the participants ($N = 18$) indicated that they noticed differences between the meals. Of the participants who noticed differences, the answers on the question 'Please explain the difference you have noticed between the two pasta salads' mostly denoted differences in satiation/how much they could eat from the pasta salads, the taste, and, to a lesser extent, the dryness of the pasta salads. On the question 'In what way, do you think, were the pasta salads different?' participants mostly commented that they thought the dough of the pasta was different. The second most prevalent comment was that they did not think the salads were different, and the third and fourth most prevalent comments were that there were differences in the dressing/herbs that were used, and that there were more or fewer tomatoes in the salad. An equal number of participants indicated a preference for the light and filling pasta salad (*N* = 7 for both salads), while 23 participants indicated no preference.

Discussion

In this study, we investigated the influence of labels denoting the satiating power of a meal on intake. The results show that, as hypothesized, intake of the test meal (pasta salad) was larger when it was labelled as a ‘light’ meal than when it was labelled as ‘filling’. Equal changes in hunger for both label conditions and a more pronounced increase in fullness in the ‘filling’ condition (sample without plate clearers) suggest that the label manipulation affected subjective satiation. Within the context of a difference in intake, similar SSS in both conditions also suggests that the labels affected the amount participants could consume for a particular hedonic change. However, when the change scores for liking and desire to eat were corrected for the amount consumed (which can be expected to correlate with sensory exposure), no effect of the labels was present. This suggests that the effect of the labels on food intake is not, or only partially, mediated by SSS.

While studies investigating the effects of nutrition labels on food intake have reported mixed findings (see e.g., Oostenbach et al., 2019), the present study demonstrates that labels specifically informing consumers of the satiating capacity of a food can affect consumption. The effect of our labels denoting satiation power on food intake extends earlier findings showing that expected satiation affects portion-size selection and food intake (see e.g., Wilkinson et al., 2012). It should be noted, though, that we did not measure expected satiation of the test meal directly, and therefore, we can only indirectly infer that our labels affected expected satiation.

Our finding that SSS (in terms of liking and desire to eat) did not differ between the label conditions despite differences in intake is in line with results of Zuraikat et al. (2018), who found that participants consumed more when served larger portions for a similar change in how much of that food they would like to eat. Perhaps serving a larger portion or manipulating beliefs about satiating power with labels affects the anticipated consumption amount, which in its turn affects the development of SSS. Our results and the effect of portion size on SSS (Zuraikat et al., 2018) suggest that SSS is generally flexible and can be overridden by other internal or external factors. Therefore, as a driver of meal termination, SSS is presumably secondary to other factors. The results of this study additionally showed that expectations about satiating qualities of a meal did not affect SSS per gram of food eaten. It should be noted that the absence of an effect of the satiation labels on SSS when corrected for amount eaten might be due to the relatively small difference in intake of the meal. Perhaps the self-report measure (VAS) of ‘liking’ and ‘desire to eat’ is simply not sensitive enough to detect any differences in SSS in light of an (approximately) 10% difference in intake. Furthermore, we cannot rule out the possibility that the labels affected meal duration, bite size, and time in between bites, since this was not measured in this study.

A limitation of our study design is the absence of a control (no label) condition in which participants were not provided with any information about the meal. Due to this study design, the results do not provide evidence as to whether the filling label decreased intake or the light label increased consumption relative to a 'control' situation (or both). Future research should determine the effects of a label denoting satiating power on intake as opposed to the absence of such information by adding a (no label) control condition. A second limitation of this study is its short-term nature (food intake was only measured for a single test meal). Therefore, we cannot rule out the possibility that participants might have compensated for variations in energy intake in subsequent meals. However, in general, individuals do not tend to compensate energy intake across meals (see e.g., Levitsky et al., 2019). Additionally, the effect of labels may be moderated by prior knowledge (e.g., satiety expectations) of the product, implying that a label denoting the satiating power of a product might be more influential for an unknown product than for a (highly) familiar product (see e.g., Hovard & Yeomans, 2015; Brunstrom et al., 2008; Brunstrom et al., 2011).

This is one of the first studies to investigate the effect of information about the satiating value of a food on intake, and, additionally we explored the effect of providing such information on SSS. In sum, this study shows that intake can be influenced by presenting information about the satiating power of a food or meal. This may be relevant for situations in which one would want to promote intake, such as maintaining adequate energy intake in vulnerable patient populations or in older persons. Additionally, the study results warrant caution in the use of labels (possibly denoting satiating power) for products intended to decrease energy intake or support weight loss (e.g., light products).

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References

Aguinis, H., Gottfredson, R. K., & Joo, H. (2013). Best-practice recommendations for defining, identifying, and handling outliers. *Organizational Research Methods*, *16*(2), 270–301. http://doi.org/10.1177/1094428112470848

Andrews, J. C., Netemeyer, R. G., & Burton, S. (2009). The nutrition elite: do only the highest levels of caloric knowledge, obesity knowledge, and motivation matter in processing nutrition ad claims and disclosures? *Journal of Public Policy & Marketing*, *28*(1), 41–55. https://doi.org/10.1509/jppm.28.1.41

Bowen, D., Green, P., Vizenor, N., Vu, C., Kreuter, P., & Rolls, B. (2003). Effects of fat content on fat hedonics: cognition or taste? *Physiology & Behavior*, *78*(2), 247–253. https://doi.org/10.1016/S0031-9384(02)00973-3

Breck, A., Cantor, J., Martinez, O., & Elbel, B. (2014). Who reports noticing and using calorie information posted on fast food restaurant menus? *Appetite*, *81*, 30–36. https://doi.org/10.1016/j.appet.2014.05.027

Brown, H. M., Rollo, M. E., De Vlieger, N. M., Collins, C. E., & Bucher, T. (2018). Influence of the nutrition and health information presented on food labels on portion size consumed: a systematic review. *Nutrition Reviews*, *76*(9), 655–677. https://doi.org/10.1093/nutrit/nuy019

Brunstrom, J. M. (2014). Mind over platter: pre-meal planning and the control of meal size in humans. *International Journal of Obesity*, *38*, 9–12. https://doi.org/10.1038/ijo.2014.83

Brunstrom, J. M., Brown, S., Hinton, E. C., Rogers, P. J., & Fay, S. H. (2011). ‘Expected satiety’ changes hunger and fullness in the inter-meal interval. *Appetite*, *56*(2), 310–315. https://doi.org/10.1016/j.appet.2011.01.002

Brunstrom, J. M., Shakeshaft, N. G., & Scott-Samuel, N. E. (2008). Measuring ‘expected satiety’ in a range of common foods using a method of constant stimuli. *Appetite*, *51*(3), 604–614. https://doi.org/10.1016/j.appet.2008.04.017

Chambers, L., McCrickerd, K., & Yeomans, M. R. (2015). Optimising foods for satiety. *Trends in Food Science & Technology*, *41*(2), 149–160. https://doi.org/10.1016/j.tifs.2014.10.007

Ebneter, D. S., Latner, J. D., & Nigg, C. R. (2013). Is less always more? The effects of low-fat labeling and caloric information on food intake, calorie estimates, taste preference, and health attributions. *Appetite*, *68*, 92–97. https://doi.org/10.1016/j.appet.2013.04.023

Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*Power 3: a flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods*, *39*(2), 175–191. https://doi.org/10.3758/BF03193146

Forde, C. G., Almiron-Roig, E., & Brunstrom, J. M. (2015). Expected satiety: application to weight management and understanding energy selection in humans. *Current Obesity Reports*, *4*, 131–140. https://doi.org/10.1007/s13679-015-0144-0

Guillocheau, E., Davidenko, O., Marsset-Baglieri, A., Darcel, N., Gaudichon, C., Tomé, D., & Fromentin, G. (2018). Expected satiation alone does not predict actual intake of desserts. *Appetite*, *123*, 183–190. https://doi.org/10.1016/j.appet.2017.12.022

Higgs, S., Williamson, A. C., Rotshtein, P., & Humphreys, G. W. (2008). Sensory-specific satiety is intact in amnesics who eat multiple meals. *Psychological Science*, *19*(7), 623–628. https://doi.org/10.1111/j.1467-9280.2008.02132.x

Hovard, P., & Yeomans, M. R. (2015). Assimilation of healthy and indulgent impressions from labelling influences fullness but not intake or sensory experience. *Flavour*, *4*(28), 1–13. https://doi.org/10.1186/s13411-015-0038-9

Lakens, D. (2013). Calculating and reporting effect sizes to facilitate cumulative science: a practical primer for t-tests and ANOVAs. *Frontiers in Psychology*, *4*, 863. https://doi.org/10.3389/fpsyg.2013.00863

Levitsky, D. A., Sewall, A., Zhong, Y., Barre, L., Shoen, S., Agaronnik, N., LeClair, J-L., Zhuo, W., & Pacanowski, C. (2019). Quantifying the imprecision of energy intake of humans to compensate for imposed energetic errors: a challenge to the physiological control of human food intake. *Appetite*, *133*, 337–343. https://doi.org/10.1016/j.appet.2018.11.017

McCann, M. T., Wallace, J. M. W., Robson, P. J., Rennie, K. L., McCaffrey, T. A., Welch, R. W., & Livingstone, M. B. E. (2013). Influence of nutrition labelling on food portion size consumption. *Appetite*, *65*, 153–158. https://doi.org/10.1016/j.appet.2013.02.013

Methven, L., Allen, V. J., Withers, C. A., & Gosney, M. A. (2012). Ageing and taste. *Proceedings of the Nutrition Society*, *71*(4), 556–565. https://doi.org/10.1017/S0029665112000742

Miller, D. L., Bell, E. A., Pelkman, C. L., Peters, J. C., & Rolls, B. J. (2000). Effects of dietary fat, nutrition labels, and repeated consumption on sensory-specific satiety. *Physiology & Behavior*, *71*(1–2), 153–158. https://doi.org/10.1016/S0031-9384(00)00319-X

Oostenbach, L. H., Slits, E., Robinson, E., & Sacks, G. (2019). Systematic review of the impact of nutrition claims related to fat, sugar and energy content on food choices and energy intake. *BMC Public Health*, *19*, 1296. https://doi.org/10.1186/s12889-019-7622-3

Rijksinstituut voor Volksgezondheid en Milieu (RIVM). NEVO online version 2019/6.0, (Bilthoven: RIVM, 2019). Retrieved from https://nevo-online.rivm.nl

Roefs, A., & Jansen, A. (2004). The effect of information about fat content on food consumption in overweight/obese and lean people. *Appetite*, *43*(3), 319–322. https://doi.org/10.1016/j.appet.2004.05.002

Rolls, B. J. (2018). The role of portion size, energy density, and variety in obesity and weight management. In T. A. Wadden & G. A. Bray (Eds.), *Handbook of Obesity Treatment* (Second Edition, pp. 93-104). The Guilford Press.

Rolls, B. J., Andersen, A. E., Moran, T. H., McNelis, A. L., Baier, H. C., & Federoff, I. C. (1992). Food intake, hunger, and satiety after preloads in women with eating disorders. *The American Journal of Clinical Nutrition*, *55*(6), 1093–1103. https://doi.org/10.1093/ajcn/55.6.1093

Rolls, B. J., & McDermott, T. M. (1991). Effects of age on sensory-specific satiety. *The American Journal of Clinical Nutrition*, *54*(6), 988–996. https://doi.org/10.1093/ajcn/54.6.988

Rolls, B. J., Rolls, E. T., Rowe, E. A., & Sweeney, K. (1981). Sensory specific satiety in man. *Physiology & Behavior*, *27*(1), 137–142. https://doi.org/10.1016/0031-9384(81)90310-3

RStudio Team (2021). RStudio: Integrated Development Environment for R. RStudio, PBC, Boston, MA. URL http://www.rstudio.com/

van Strien, T., Frijters, J. E. R., Bergers, G. P. A., & Defares, P. B. (1986). The Dutch Eating Behavior Questionnaire (DEBQ) for assessment of restrained, emotional, and external eating behavior. *International Journal of Eating Disorders*, *5*(2), 295–315. https://doi.org/10.1002/1098-108X(198602)5:2<295::AID-EAT2260050209>3.0.CO;2-T

Wilkinson, L. L., Hinton, E. C., Fay, S. H., Ferriday, D., Rogers, P. J., & Brunstrom, J. M. (2012). Computer-based assessments of expected satiety predict behavioural measures of portion-size selection and food intake. *Appetite*, *59*(3), 933–938. https://doi.org/10.1016/j.appet.2012.09.007

Yeomans, M. R. (2015). Cued satiety: how consumer expectations modify responses to ingested nutrients. *Nutrition Bulletin*, *40*(2), 100–103. https://doi.org/10.1111/nbu.12139

Zuraikat, F. M., Roe, L. S., Smethers, A. D., & Rolls, B. J. (2018). Doggy bags and downsizing: packaging uneaten food to go after a meal attenuates the portion size effect in women. *Appetite*, *129*, 162–170. https://doi.org/10.1016/j.appet.2018.07.009

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The relative importance of complexity, variety, and portion size in ice cream preference in Dutch and American participants

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Abstract

Food variety, complexity, and portion size each influence food choice and consumption, but their relative importance is poorly understood. In two online choice-experiments, we investigated the relative importance of variety, complexity, and portion size in consumer preferences by systematically varying ice cream offerings. Complexity was defined as the presence of different components within a scoop (e.g., chunks or flavours), while variety was defined as combinations of ice cream scoops that differ in flavour and/or texture. Two choice-based conjoint questionnaires were presented to 498 Dutch (50.8% females) and 502 American (52.6% females) consumers aged between 18 and 65 years. Study 1 tested the relative importance of complexity and variety in consumer preferences, while Study 2 tested the relative importance of variety and portion size in preferences. Participants chose their preferred option when presented with various ice cream options showing different levels of variety and complexity (Study 1), or different levels of variety and portion sizes (Study 2). Across countries, variety was a stronger driver of ice cream preference than complexity, but the most preferred ice cream options were both varied and complex. Further, across countries, flavour was more important than portion size, and again a variety of flavours was the most preferred. Finally, American participants overall preferred larger portion sizes than did Dutch participants. These data indicate variety is a key determinant of food preference, at least within the context of ice cream, for consumers in both the Netherlands and the United States.

Introduction

Food complexity, food variety and portion size all influence food preference, choice and consumption (e.g., Mielby et al., 2012; Palczak et al., 2019; Parizel et al., 2017; Zuraikat et al., 2019). Prior studies have investigated the influence of complexity, variety and portion size as separate drivers of food intake and selection, but under naturalistic conditions, these factors work together to influence food selection simultaneously. Here, we aimed to specifically determine the relative importance of complexity, variety and portion size within a realistic online choice task.

Perceived complexity is an important determinant of food preference (e.g., Spence, 2018) and selection (Palczak et al., 2019; Vabø & Hansen, 2014). However, data on the relationship between complexity and hedonic responses conflict (e.g., Palczak et al., 2019; Mielby et al., 2012; Lévy et al., 2006; Soerensen et al., 2015; Weijzen et al., 2008; Stolzenbach et al., 2016; Porcherot & Issanchou, 1998; Giacalone et al., 2014). For example, Soerensen et al. (2015) found no relationship between perceived complexity and liking for chocolate products, while Weijzen et al. (2008) found more complex soups and snacks were liked more than less complex options. Porcherot and Issanchou (1998) reported a negative correlation between liking and the difficulty to describe flavoured crackers, but they did not find any evidence of a correlation between liking and perceived number of components. Given these mixed findings, it is important to note that researchers have defined complexity in different ways (see e.g., Palczak et al., 2020; Marcano et al., 2015; Spence, 2018), which may explain the divergent findings. For additional discussion of the definition and operationalization of complexity, see Palczak et al. (2019), and Spence and Wang (2018). The conflicting evidence as summarized above clearly shows that the relationship between complexity and preference is still poorly understood.

Just as complexity has been inconsistently defined, the definition of variety has also varied substantially across studies (for a more detailed discussion, see Raynor & Vadiveloo, 2018). Despite the absence of a consistent definition of variety, generally, controlled feeding studies support the existence of a variety effect, where more food is eaten when greater variety is offered (Embling et al., 2021; Rolls, Rowe, et al., 1981). Furthermore, multiple studies have found that variety within a meal is linked to increased liking (e.g., Wilkinson et al., 2013; Van Wymelbeke et al., 2020; Parizel et al., 2017; but see Wijnhoven et al., 2015; Divert et al., 2015). Lähteenmäki and Van Trijp (1995) investigated the effect of within-meal variety on choice behaviour. In their study, Finnish young adults chose sandwiches to eat for lunch from eight different sandwiches (different fillings) in six experimental sessions. They found that within each session variety was high – that is, participants ate different fillings within one session. Although there is strong evidence that variety enhances food intake (the variety effect), its relationship with food liking and preference is less evident.

While complexity and variety have been studied in relation to food preference and liking to some extent, portion size has been studied primarily in relation to food intake.

Multiple studies show that people eat more when served larger portions (for a review of the portion size effect, see Zuraikat et al., 2019). Evidence of a relationship between portion size and food choice or preference is scarce (see e.g., Reily & Vartanian, 2016). In a qualitative study conducted by Vermeer et al. (2010), participants expressed that larger portion sizes usually provide more value for money, which indicates that portion size in some cases might affect product choices due to cost/money considerations (see also Steenhuis & Poelman, 2017). Furthermore, portion size preferences are affected by the 'standard' that consumers are exposed to (see Robinson & Kersbergen, 2018), which are likely to differ between countries or cultures (see e.g., Young & Nestle, 2002; Rozin et al., 2003; Young & Nestle, 2007; Steenhuis et al., 2009). However, the role portion size plays in food selection and cultural influences on preference for food portions remain to be determined.

Prior studies have shed some light on the relationship between complexity, variety and portion size and food preference or choice, but these food properties have not been studied together (as far as we know). In natural eating situations, the level of complexity, variety and portion size varies within a food or meal, exerting influence on food intake and choice relative to each other. Furthermore, food preferences might differ between cultures. Therefore, in two studies, we investigated how complexity, variety and portion size relate to each other with regard to ice cream preference in a cross-cultural consumer sample. As mentioned, complexity and variety have not been clearly defined and are sometimes even described identically (e.g., one food with several sensory qualities). In our studies, food complexity is defined as the presence of several components in a food item (specifically, chunks or different flavours within one ice cream scoop), while food variety is the combination of scoops of ice cream, differing in flavour or texture.

We conducted two online choice experiments to answer the following research questions: (1) 'What is more important in consumer preferences for ice cream: complexity or variety?', and (2) 'How important are variety and portion size (relative to each other) in ice cream preferences?'. To answer these research questions, two choice-based-conjoint (CBC) questionnaires were presented to consumers in the Netherlands and the United States; one testing consumer preferences with regard to complexity and variety (Study 1) and the other testing the relative importance of variety and portion size regarding ice cream preferences (Study 2). CBC experiments are typically used to investigate participants' preferences for features (and their combinations) for all sorts of products (Sawtooth Software, n.d.). In a CBC experiment, participants are asked to choose the preferred option when presented with a number of product concepts. Here, participants were asked to choose between several ice cream options, that were experimentally manipulated to vary in level of variety and complexity, or variety and portion size.

For Study 1, we hypothesized that participants choosing between ice creams that were either complex and varied, only varied, only complex, or neither, would choose the product that is the most complex and varied the most. The varied product would be second in preference and the complex product third – that is, we expected that variety would be a stronger driver of preference than complexity, at least as defined here. The 'simplest' product would be the least preferred. For Study 2 on the relative importance of variety and portion size, we hypothesized variety would be a stronger driver of preference than portion size for Dutch participants (but the varied and largest option would be the most preferred). Also, we expected that the American participants would choose larger portion sizes over variety (i.e., portion size would be a stronger driver of preference than variety) due to the general belief that 'bigger is better'.

Methods

The two studies were preregistered on The Open Science Framework (OSF) (https://osf.io/zm4s9), and all procedures were approved by the Office for Research Protections of The Pennsylvania State University (ref: STUDY00015897). The two CBC experiments were presented in a single survey, created using Sawtooth Software's Lighthouse Studio (Academic Research, version 9.8.1, Provo, UT). Participants participated in both studies. Therefore, the study procedure is described for the entire survey, including both CBC experiments. Supplemental materials can be found on OSF (https://osf.io/4m9rh/?view_only=).

Participants

Participants were recruited in the Netherlands (NL) and the United States (US) using a third-party market research provider (Dynata LLC) who has local offices in both countries; they remunerated participants according to their standard rates for each location. Participants in the two studies were 502 American and 498 Dutch males (N^{US} = 238, N^{NL} = 245) and females (N^{US} = 264, N^{NL} = 253), aged between 18 and 65 years old (M^{US} = 38.8, SD^{US} = 12.9; M^{NL} = 41.9, SD^{NL} = 13.2). The mean BMI was 29.7 (*SD* = 8.5) for the American sample and 25.5 (*SD* = 5.3) for the Dutch sample. Supplemental Tables S1 and S2 detail additional characteristics of the cohorts in each country. Participants were excluded from the study if they had not consumed ice cream at least once in the past thirty days.

Survey

Participants in the study completed an online survey consisting of the two CBC experiments, as well as demographics and eating behaviour questions. Prior to participation in the study commenced, written information about the study procedure and aim (not the hypotheses) were given, after which interested participants indicated consent. Next, participants were screened to make sure they met the inclusion criteria. Eligible participants were then directed to complete the study surveys. Attention checks were incorporated in the surveys to ensure that participants were reading the instructions and questions carefully. Completers (*n* = 1000) were defined as individuals who completed all attention checks correctly.

CBC experiments

Two separate CBC experiments were included in the online survey, which were presented in random order; one showing ice cream options that ranged in variety and complexity (Study 1), and the other showing options that ranged in variety and portion size (Study 2). The CBC experiments were tailored to personal ice cream flavour preference; before starting the CBC experiments, participants were asked to choose their preferred flavour from three options (vanilla, chocolate, and strawberry) and their preferred flavour combination from a list of combinations of these three flavours (chocolate and vanilla; chocolate and strawberry; strawberry and vanilla). They then completed a version of the CBC experiment that presented only ice cream options that contained their most preferred flavour combination. In the Dutch sample, 218 participants completed the 'chocolate and vanilla' version, 111 completed the 'chocolate and strawberry' version, and 169 completed the 'strawberry and vanilla' version. For the American sample, these counts were 260, 98, and 144, respectively. Each CBC experiment (Study 1 or 2) contained 10 individual CBC tasks; in each task, three products were shown, along with a 'none of these' option, and participants were asked to choose their most preferred option. In general, participants were fairly familiar with the flavours and combinations presented in the CBC tasks (see supplemental Table S3). Each participant completed 20 CBC tasks in total (10 each for Study 1 and Study 2).

To set a realistic context for the choice task, the following instruction accompanied the complexity-variety CBC experiment: 'Imagine it is a hot summer day and you have a voucher to get 2 scoops of ice cream, in a dish, from your local ice cream shop. From the following options please select the ice cream you would prefer'. The complexity-variety CBC experiment (Study 1) contained ice cream options that varied in two attributes: flavour and sustainability. A distractor attribute (sustainability) was included so that participants would not infer the research question, and to create a sufficient number of vignettes to present to the participants. This attribute is not included in the analysis nor discussed in the results section of this paper (see supplemental Table S6 for sustainability preference patterns in Study 1). The attribute flavour contained ten levels that can be categorized into: 'no complexity & no variety' (two scoops of one basic flavour), 'complexity' (two scoops of the same complex flavours), 'variety' (two scoops of two different basic flavours), 'complexity & low variety' (one complex flavour and one basic flavour, the same flavour), 'complexity & variety' (two different flavours, at least one complex). The sustainability levels were: organic, natural, and locally produced. The attributes and levels of the complexity-variety CBC experiment (Study 1) are summarized in Table 1. Figure 1 shows an example of a choice task within Study 1.

Table 1. Attributes and levels of complexity-variety CBC (Study 1). All levels of both attributes were combined and randomly presented to participants.

Chocolate - Strawberry		
Attribute	**Flavour**	**Sustainability**
Levels	Strawberry	Organic
	Chocolate	Natural
	Strawberry & Chocolate	Locally produced
	Strawberry with pieces	
	Chocolate with chips	
	Strawberry & Strawberry with pieces	
	Chocolate & Chocolate with chips	
	Strawberry with pieces & Chocolate	
	Chocolate with chips & Strawberry	
	Strawberry with pieces & Chocolate with chips	
Chocolate - Vanilla		
Attribute	**Flavour**	**Sustainability**
Levels	Vanilla	Organic
	Chocolate	Natural
	Chocolate & Vanilla	Locally produced
	Chocolate with chips	
	Vanilla-chocolate swirl	
	Vanilla & Vanilla-chocolate swirl	
	Chocolate & Vanilla-chocolate swirl	
	Chocolate & Chocolate with chips	
	Vanilla & Chocolate with chips	
	Vanilla-chocolate swirl & Chocolate with chips	
Vanilla - Strawberry		
Attribute	**Flavour**	**Sustainability**
Levels	Vanilla	Organic
	Strawberry	Natural
	Vanilla & Strawberry	Locally produced
	Strawberry with pieces	
	Vanilla-strawberry swirl	
	Vanilla & Vanilla-strawberry swirl	
	Strawberry & Vanilla-strawberry swirl	
	Strawberry & Strawberry with pieces	
	Vanilla & Strawberry with pieces	
	Vanilla-strawberry swirl & Strawberry with pieces	

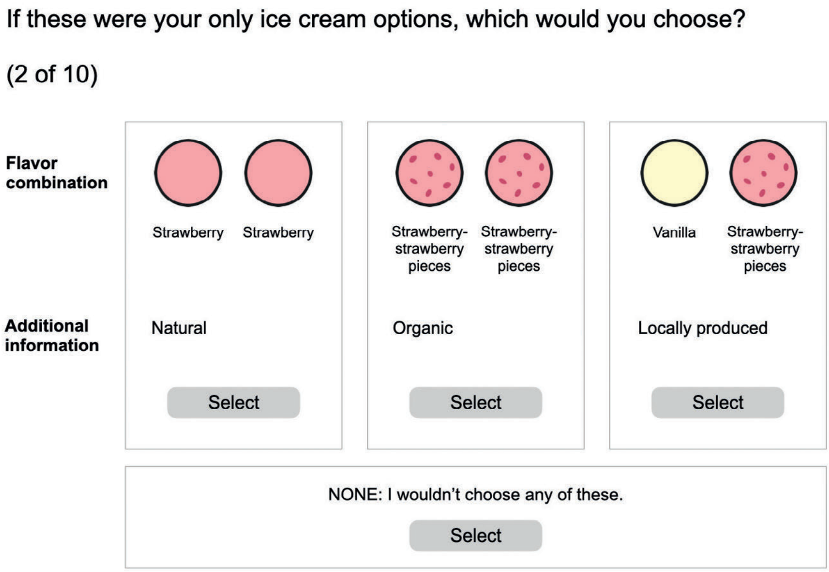

Figure 1. Example of choice task Study 1 (complexity-variety).

Before commencing with the variety-portion size CBC experiment (Study 2), the following instruction was shown: 'You will now answer some additional choice-based questions about your ice cream preferences' (due to a programming error, the instructions for each CBC experiment were not always presented with the corresponding CBC). The attributes and levels of the variety-portion size CBC experiment were flavour (three levels: flavour 1, flavour 2, both flavours combined), portion size (three levels: small, medium, large), and sustainability (three levels: organic, natural, locally produced). Again, the sustainability attribute is not included in the analysis and results of this paper (see supplemental Table S7 for sustainability preference patterns in Study 2). The attributes and levels of Study 2 are outlined in Table 2. Figure 2 shows an example of a choice task within Study 2.

Table 2. Attributes and levels of variety-portion size CBC (Study 2). All levels of both attributes were combined and randomly presented to participants.

Chocolate - Strawberry			
Attribute	**Flavour**	**Portion size**	**Sustainability**
Levels	Strawberry	Small	Organic
	Chocolate	Medium	Natural
	Strawberry & Chocolate	Large	Locally produced
Chocolate - Vanilla			
Attribute	**Flavour**	**Portion size**	**Sustainability**
Levels	Vanilla	Small	Organic
	Chocolate	Medium	Natural
	Vanilla & Chocolate	Large	Locally produced
Vanilla - Strawberry			
Attribute	**Flavour**	**Portion size**	**Sustainability**
Levels	Strawberry	Small	Organic
	Vanilla	Medium	Natural
	Strawberry & Vanilla	Large	Locally produced

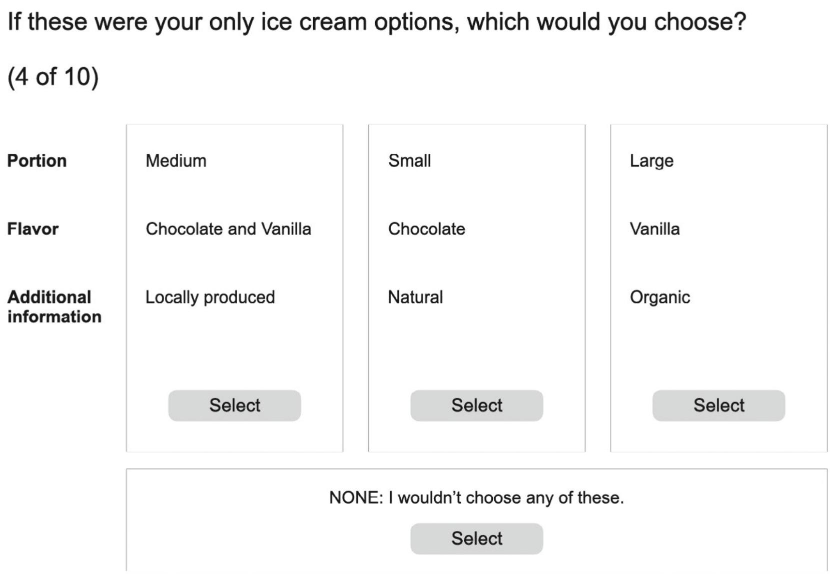

Figure 2. Example of choice task Study 2 (variety-portion size).

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Demographics and eating behaviour

In addition to completing the CBC experiments, participants were asked to answer several questions assessing demographic and eating behaviour characteristics. Participants indicated their age, sex, height and weight, nationality, state of residence (relevant for American participants only), race (assessed for American participants only), ethnicity (assessed for American participants only), whether they had been diagnosed with an eating disorder or had been diagnosed in the past, whether they were currently on a diet to gain or lose weight, and their educational level. Furthermore, they indicated the strength of their flavour and flavour-combinations preferences, how familiar the presented ice cream options were to them, and how hungry they felt. They also completed the external eating and restraint scale of the Dutch eating behavior questionnaire (DEBQ; range of possible values: 1 – 5; Van Strien et al., 1986), and the VARSEEK-scale (variety seeking tendency with respect to foods; range of possible values: 8 – 40; van Trijp & Steenkamp, 1992). Furthermore, pictures of ice cream portion sizes – ranging from one to six scoops – were shown to participants and they were asked to indicate what they considered to be a small, medium, and large portion size and how often they usually choose each size.

Statistical analysis

The data were collected and analysed using vendor provided tools in Lighthouse Studio from Sawtooth Software and in Rstudio (RStudio Team, 2021) with packages 'pastecs', 'psych', 'gmodels', 'ggplot2', 'ez', 'car', 'plyr', 'dplyr', 'reshape', and 'reshape2'. The data were analysed separately per country and CBC version (based on preferred flavour combination). In Lighthouse, Hierarchical Bayes (HB) estimation was used to determine the overall relative importance of the attributes (expressed as a percentage), and to calculate zero-centred difference utility scores for total utility and individual scores for each participant for each attribute level. Attribute importance indicates the relative importance of each attribute (e.g., portion size), which sum to 100%. Zero-centred difference utility scores indicate relative preference for levels within an attribute (e.g., medium in attribute portion size). The more positive the score the more preferable the attribute level is.

For both studies, we performed Latent Class Analysis in Lighthouse to explore whether any consumer segments could be identified based on choice behaviour. Additionally, HB results were clustered based on demographic and eating behaviour characteristics to explore the influence of age (segments: 18-24, 25-39, 40-54, and 55-65 years), sex (male vs. female), BMI class (calculated from self-reported height and weight: underweight, normal weight, overweight, and obese), hunger (hungry, neutral, full), external eating (low vs. high; median split, $median^{US} = 3.1$, $median^{NL} = 3$), restraint (low vs. high; median split, $median^{US} = 2.8$, $median^{NL} = 3$), and variety seeking (low vs. high; median split, $median^{US} = 26$, $median^{NL} = 26.5$). Participants who reported heights smaller than 70 cm or 27.5 inches or larger than 90.5 inches, weights smaller than 30 kg or 66.1 pounds, and BMI values smaller than 17 or larger than 70 kg/m^2 were excluded from the analysis exploring the influence of BMI. Of the 502 American participants, 143 were excluded from the exploratory analysis for this reason and of the 498 Dutch participants, 19 were excluded. The spreadsheets that were used for these exploratory analyses are available upon request.

Results

Study 1 – variety and complexity

The goal of Study 1 was to determine whether complexity or variety is more preferred in ice cream selection. For Study 1, a stable choice pattern was observed across countries and flavour combinations, therefore attribute importance and utility score patterns are discussed for the entire sample (both countries, all flavour combinations). First, we checked the importance of the attributes flavour (levels of complexity and variety) and sustainability. Table 3 shows that flavour was more important than sustainability. Next, preferences for levels of variety and complexity were determined. Total utility scores for all ice cream options in the flavour attribute, clustered by levels of variety and complexity, are shown in Figure 3, separated by country and flavour combination. Mean total utility values for all presented ice cream options can be found in supplemental Table S4. Overall, the most complex and varied ice cream options were the most preferred, while varied options were generally more preferred than complex options, suggesting that variety is more preferred than complexity, regardless of country or flavour combination. Options lacking both variety and complexity were least preferred.

Table 3. Relative attribute importance (%) for the attributes included in Study 1 (complexity-variety), by country and flavour combination.

	Chocolate – Strawberry	**Chocolate – Vanilla**	**Vanilla – Strawberry**
The United States			
Flavour	77.1	79.3	79.9
Sustainability	22.9	20.7	20.2
The Netherlands			
Flavour	80.7	80	77.7
Sustainability	19.3	20	22.3

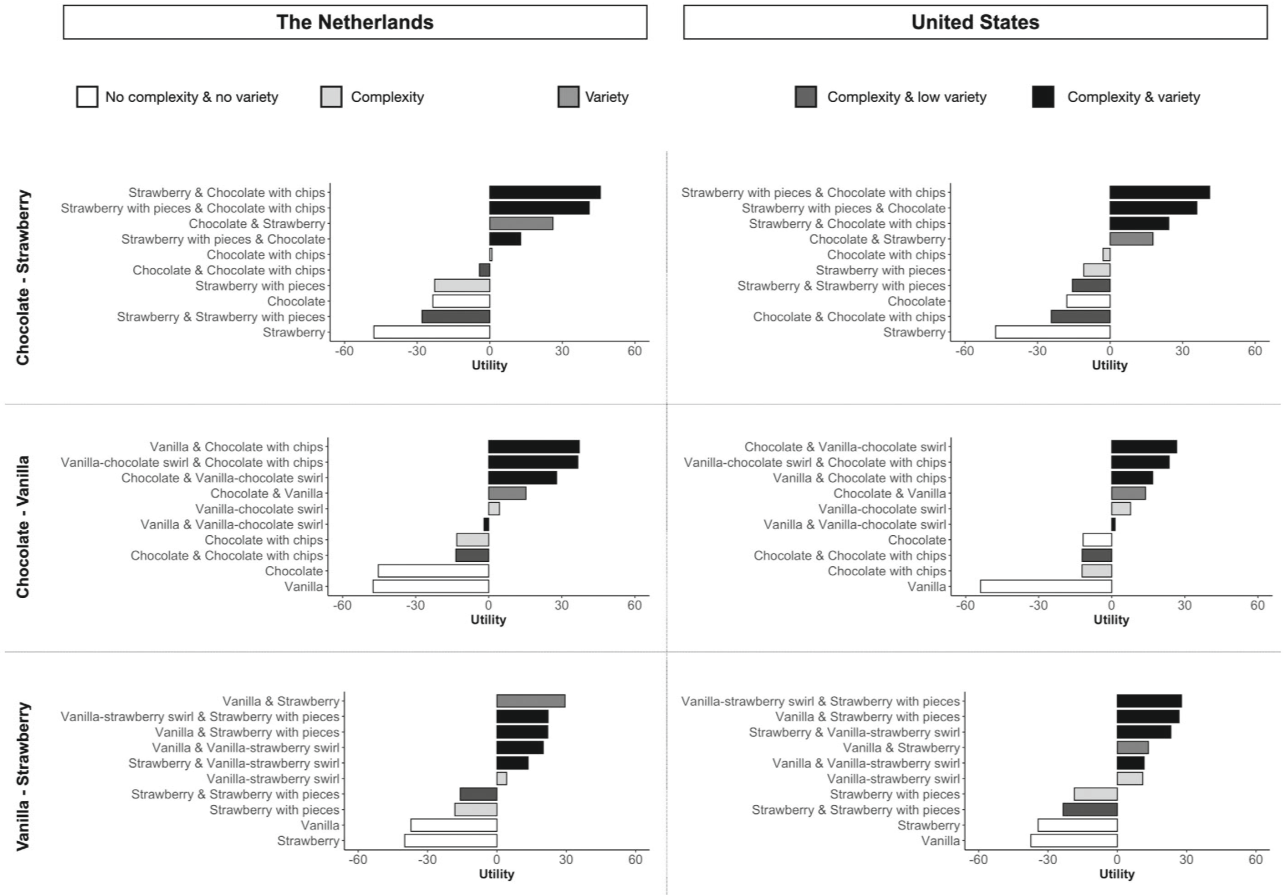

Figure 3. Utility scores for flavour attribute levels in Study 1 (complexity-variety), separated by country and flavour combination.

Exploratory analyses

Latent Class Analyses performed on both the Dutch and the American data did not reveal any consumer segments based on choice behaviour. Separating the data based on age segment, sex, BMI class, hunger, external eating, restraint and variety seeking did not impact the preference patterns for both the Dutch and American consumers.

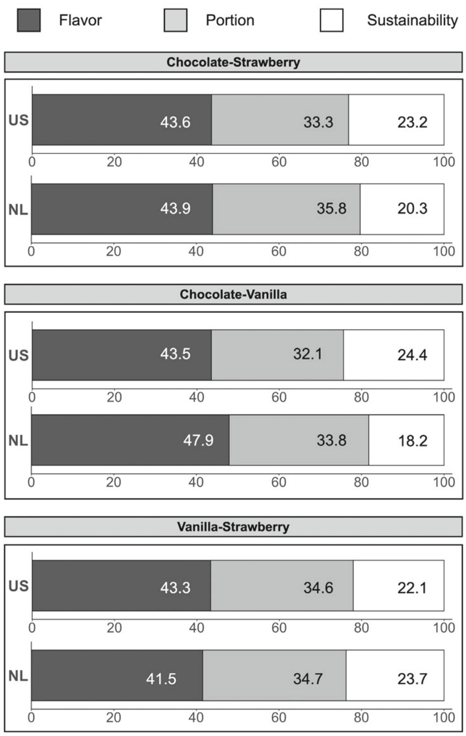

Figure 4. Relative attribute importance (%) for attributes in Study 2 (variety-portion size), by country (US = the United States, NL = the Netherlands) and flavour combination.

Study 2 – variety and portion size

In study 2, we aimed to determine whether variety or portion size was more important for ice cream selection. Figure 4 shows the relative importance of the attributes in the variety and portion size CBC experiment (Study 2). Across countries and flavour combinations, flavour was the most important attribute, followed by portion size. Sustainability was the least important attribute. Within the attribute flavour, the combination of two flavours (i.e., variety) was the most preferred, across countries and flavour combinations (see Figure 5). In contrast, for the portion size attribute, different preference patterns emerged per country (see Figure 6). Dutch participants preferred the medium portion size across all flavour combinations, while American participants generally preferred large portion sizes. For the flavour combinations ‘chocolate and strawberry’ and ‘vanilla and strawberry’, large portion sizes were clearly preferred. However, for the flavour combination ‘chocolate and vanilla’, large portion sizes were only slightly preferred over medium portion sizes. Across both countries and flavour combinations, small portion sizes were the least preferred. See supplemental Table S5 for the total utility values for both the flavour and portion size attribute.

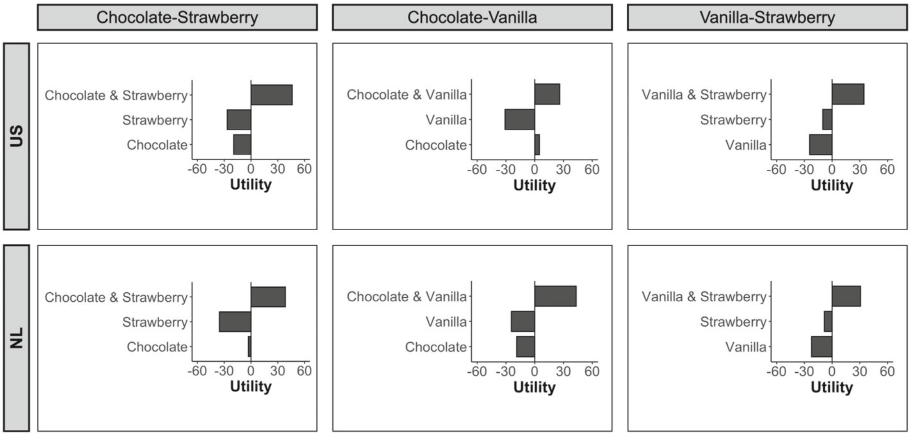

Figure 5. Utility scores for levels within the attribute flavour (Study 2, variety-portion size) separated by country (US = the United States, NL = the Netherlands) and flavour combination. In all six panels, the variety condition is most preferred, regardless of the specific flavour combination.

Because the expectation of small, medium, and large portions might vary across countries, we asked participants to indicate how many scoops of ice cream would constitute each size after the CBC portion of the survey was complete. These data are shown in Table 4. For both countries, most participants chose 1 or 2 scoops to represent small portion sizes, 3 or 4 scoops to represent medium portion sizes and 5 or 6 scoops to represent large portion sizes. This suggests that American consumers indeed prefer larger portion sizes of ice cream than Dutch participants. Furthermore, Table 5 shows that an approximately equal proportion of the American and Dutch participants (26% and 27%, respectively) indicated they choose a small portion ‘most of the time’ or ‘always’. The proportion of American participants choosing medium portion sizes ‘most of the time’ or ‘always’ was 40% as compared to 59% for Dutch participants. The large portion size was chosen by 38% of the American participants and 28% of the Dutch participants ‘most of the time’ or ‘always’. Thus, stated (declared) habits align with the revealed preferences from the CBC experiment (note that declared habits are not compared directly with individual utility scores).

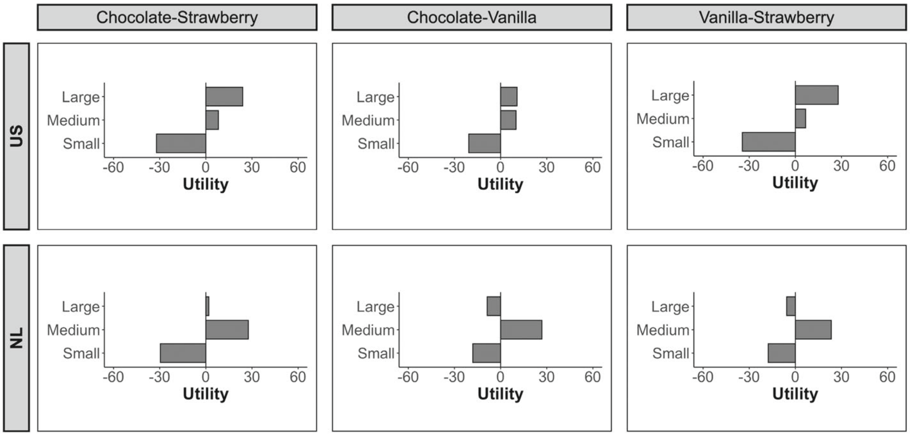

Figure 6. Utility scores for levels within the attribute portion size (Study 2, variety-portion size) separated by country (US = the United States, NL = the Netherlands) and flavour combination. In the top row (US) the largest portion is always most preferred, regardless of specific flavour combination. In the bottom row (NL) the medium sized portion is always most preferred, regardless of the specific flavour condition.

Table 4. Picture choices for each portion size per country. The two most chosen numbers of scoops for each portion size (small, medium, or large) are highlighted. Means and *SD*'s of number of scoops chosen for each portion size are presented in the outer right column. (US = the United States, NL = the Netherlands)

	1 scoop	2 scoops	3 scoops	4 scoops	5 scoops	6 scoops	Mean (*SD*)
US							
Small	173 (34%)	196 (39%)	74 (15%)	27 (5%)	12 (2%)	20 (4%)	2.1 (1.2)
Medium	11 (2%)	110 (22%)	209 (42%)	118 (24%)	42 (8%)	12 (2%)	3.2 (1)
Large	10 (2%)	19 (4%)	82 (16%)	97 (19%)	107 (21%)	187 (37%)	4.7 (1.3)
NL							
Small	221 (44%)	197 (40%)	45 (9%)	15 (3%)	9 (2%)	11 (2%)	1.8 (1.1)
Medium	7 (1%)	100 (20%)	224 (45%)	143 (29%)	16 (3%)	8 (2%)	3.2 (0.9)
Large	4 (1%)	13 (3%)	73 (15%)	92 (18%)	109 (22%)	207 (42%)	4.8 (1.2)

Table 5. Participants' reports of how often they choose small, medium, and large portion sizes, separated by country. Means and *SD*'s are presented in the outer right column. (US = the United States, NL = the Netherlands)

	Never (1)	**Sometimes (2)**	**Most of the time (3)**	**Always (4)**	**Mean (*SD*)**
US					
Small	96 (19%)	277 (55%)	85 (17%)	44 (9%)	2.2 (0.8)
Medium	32 (6%)	267 (53%)	173 (34%)	30 (6%)	2.4 (0.7)
Large	80 (16%)	229 (46%)	131 (26%)	62 (12%)	2.3 (0.9)
NL					
Small	102 (20%)	262 (53%)	103 (21%)	31 (6%)	2.1 (0.8)
Medium	20 (4%)	184 (37%)	261 (52%)	33 (7%)	2.6 (0.7)
Large	148 (30%)	211 (42%)	104 (21%)	35 (7%)	2.1 (0.9)

Exploratory analyses

Latent Class Analyses performed on both the American and Dutch data did not reveal any consumer segments based on choice behaviour. Separating the results on age, sex, hunger, and external eating did not alter the reported preference patterns. While no differences in portion preference patterns were found between BMI categories, preference for large portions was slightly more pronounced for participants with overweight and obesity compared to participants with normal weight for the American sample. It should be noted, though, that due to the large number of American participants who entered improbable height and weight data, separating the sample based on BMI category resulted in small samples. Interpretation of these exploratory results should therefore be regarded as preliminary. For Dutch participants, there was a trend for individuals with obesity to prefer large portions slightly more than participants with normal weight and overweight. American participants with high restraint showed a slightly less pronounced preference for large portions than American participants with low restraint, but both groups generally did not prefer small portions. A median split on variety seeking scores revealed that for American participants, high variety seekers had slightly higher utility scores for the variety ice cream options than the low variety seekers.

Discussion

In two choice experiments, we investigated the relative importance of complexity and variety (Study 1), and of variety and portion size (Study 2) in ice cream preference. Results from Study 1 showed the expected preference pattern, across both countries and all flavour-combinations. Specifically, variety was a stronger driver of preference than complexity (as operationally defined here). Conversely, the results of Study 2 did not confirm all of our hypotheses. For both the American and Dutch participants, flavour was more important than portion size, while we expected portion size to be more important than flavour for American participants. As expected, variety in flavour was preferred across countries. With regard to portion preferences, Dutch consumers preferred a medium portion size, while we expected large portions to be preferred. American consumers preferred large portion sizes, as was indeed expected. The results of both studies highlight the importance of food variety in ice cream preferences. Additionally, results of Study 1 suggest that food variety and complexity are likely to be viewed and valued as separate food characteristics by consumers. The results of Study 2 emphasize the importance of acknowledging cultural differences in food preferences, since portion size preferences differed between American and Dutch consumers.

The results of Study 1 – showing that variety is more strongly preferred than complexity – align with findings of a prior study conducted by Levitsky et al. (2012). When they presented participants with a vegetable stir-fry or pasta as a mixed meal or with the ingredients presented separately, they found that participants ate more of the meal when the ingredients were separated. Following our operationalization of variety and complexity, we would argue that the presentations of the stir-fry and pasta were either complex (mixed) or varied (separated), with the varied presentation increasing intake. However, in the Levitsky et al. (2012) study, acceptability of the meals did not correspond with our findings; participants rated the composite and separated meals as equally acceptable. It should be noted, though, that acceptability was measured at the end of the meal, and could therefore be influenced by sensory-specific satiation (a relative decline in pleasantness of a food during its consumption; Rolls, Rolls, et al., 1981). Furthermore, ratings on an acceptability scale might also just be less sensitive than a preference task. Results of two experiments conducted by Rolls, Rowe, et al. (1981) do suggest that some level of complexity is needed for variety to enhance intake. They found that serving three yogurts differing in flavour, texture and colour opposed to just one increased intake, but serving three yogurts only differing in flavour did not.

While previous studies have been inconclusive regarding the association between complexity and product liking (see Palczak et al., 2019), we observed a positive relationship between complexity and preferences in a choice task. The most preferred ice cream options were both varied and complex. Additionally, complex ice cream options were preferred over 'simple' ice cream options. Textural (e.g., chocolate chips) and visual complexity (swirls) were equally preferred, indicating that the preference for complex flavours cannot be attributed to the presence of different textures. Our finding that complex flavours were preferred over 'simple' flavours is in line with Hyde & Witherly's (1993) concept of dynamic contrast, which proposes that food that creates variety or contrast in orosensation preserves interest (i.e., palatability). More complex ice cream flavours (either in terms of texture or flavour) can be expected to deliver more dynamic contrast in orosensation, which increases liking of these flavours – in our study reflected by relative preference scores.

In Study 2, both American and Dutch participants indicated to choose portion sizes that were generally viewed as 3 scoops or larger, which can be expected in the light of earlier findings that 'large portions are appealing to consumers and drive purchases' (English et al., 2015, p. 44). The finding that American participants preferred larger ice cream portions than Dutch participants is not surprising, since American participants also reported that they choose large sizes more often than Dutch participants, who reported they choose medium sizes more often than the American participants. There is evidence that the 'usual' portion sizes that American consumers encounter in their environment are larger than those in Europe (see e.g., Young & Nestle, 2012; Young & Nestle, 2002; Rozin et al., 2003; Young & Nestle, 2007; Steenhuis et al., 2009). Perceptions of 'normal' portion sizes are influenced by what we encounter in our environment (see Robinson & Kersbergen, 2018; Young & Nestle, 2012), and as Vermeer et al. (2010) argue, exposure to larger portions leads to 'portion distortion'.

The mean BMI of our American sample was considerably higher than that of the Dutch sample (mean BMI^{US}= 29.7, mean BMI^{NL} = 25.5), which could be expected to drive the differences in preferred portion size between the countries. Large portions (of energy dense foods) have been suggested to play a causal role in the development and increasing prevalence of overweight and obesity (see e.g., Rolls, 2014; Young & Nestle, 2012). One could argue that this proposed relationship might translate to stronger preferences for large portions for individuals with overweight or obesity. However, in our study, only a slightly stronger preference for large portions was observed for individuals with overweight and obesity in the American sample and for the Dutch participants with obesity (i.e., general preference patterns were not influenced by BMI). Therefore, it is unlikely that the difference in portion size preference between the American and Dutch sample is driven by a larger number of individuals with overweight and obesity in the American sample.

Exploratory analyses did not show an influence of individual differences in measured demographics or eating behaviour on the preference patterns for complexity and variety (Study 1), but some nuanced differences were observed for the portion size and variety CBC (Study 2) with regard to BMI (as discussed above), restrained eating and variety seeking behaviour. The finding that for American participants those with high restraint showed a less pronounced preference for large portions than those with low restraint is in line with dieting intentions of restrained eaters (Polivy et al., 2020). However, this pattern was not present for the Dutch consumers. It would have been reasonable to expect that highly restrained eaters would choose the smallest available option, but perhaps the influence of restrained eating on ice cream portion preferences is limited. Variety seeking influenced variety preferences slightly for American participants in Study 2, as high variety seekers showed a slightly stronger preference for the varied ice cream options (although low variety seekers preferred these options as well). This pattern was only present for the American consumers, suggesting that there is no substantial influence of variety seeking on ice cream preference cross-culturally. Since the VARSEEK scale has been found to measure food neophilia rather than a true variety-seeking tendency for foods (see Lenglet, 2018), it is not surprising that variety-seeking scores derived from the VARSEEK did not influence preference patterns, as in our study variety was manipulated of a familiar food. The absence of pronounced influences of individual characteristics on ice cream preferences and the absence of any consumer segments based on choice behaviour (as identified by Latent Class Analysis) underlines the robustness of the presented preference patterns. It should be noted, however, that segmenting the samples based on individual characteristics occasionally led to very small segments (n < 10) for a CBC design, and that our measurements of restraint and variety seeking relied on self-report (for a discussion of the limitations of self-report, see e.g., Polivy et al., 2020).

There are some limitations of the current studies. First, in the presented CBC's, we deliberately did not include price as this allowed us to gain better insight into the appeal of variety, complexity, and portion size for consumer preferences. Of course, when ice cream is purchased, price undoubtedly affects consumer product choices (for a discussion of 'value for money' in relation to portion size choices, see Vermeer et al., 2010; see also Steenhuis & Poelman, 2017; Haws & Winterich, 2013). Second, since the conducted studies specifically investigated complexity, variety and portion size with regard to ice cream, caution must be exercised when extrapolating the results to other foods (or beverages). It is reasonable to expect that the level of preferred variety and complexity, as well as portion size preferences will depend on the product under study. Third, participants were aware that they would not be consuming the chosen products, and, due to the cross-sectional study design, influences of product consumption experiences could not be taken into account (e.g., when a chosen product does not meet expectations, this is likely to influence preferences in the next choice situation). In light of these limitations, the current results warrant replication in real-life choice situations and across different foods (or beverages).

In summary, the results of two choice experiments provide evidence that variety and complexity contribute independent and positive influences on consumer ice cream choices. Variety is more strongly preferred than complexity, but the most preferred products are both varied and complex. These preferences were stable across countries and flavour combinations, and individual differences did not exert much influence. Portion size preferences did differ cross-culturally, with American participants preferring larger portions than Dutch participants. However, portion size was less important than flavour, independent of country and flavour combination. Across both studies, variety is clearly a key determinant of ice cream preferences and perhaps of food/meal preferences in general.

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References

Divert, C., Laghmaoui, R., Crema, C., Issanchou, S., Van Wymelbeke, V., & Sulmont-Rossé, C. (2015). Improving meal context in nursing homes. Impact of four strategies on food intake and meal pleasure. *Appetite*, *84*, 139–147. https://doi.org/10.1016/j.appet.2014.09.027

Embling, R., Pink, A. E., Gatzemeier, J., Price, M., Lee, M. D., & Wilkinson, L. L. (2021). Effect of food variety on intake of a meal: a systematic review and meta-analysis. *The American Journal of Clinical Nutrition*, *113*(3), 716–741. https://doi.org/10.1093/ajcn/nqaa352

English, L., Lasschuijt, M., & Keller, K. L. (2015). Mechanisms of the portion size effect. What is known and where do we go from here? *Appetite*, *88*, 39–49. https://doi.org/10.1016/j.appet.2014.11.004

Giacalone, D., Duerlund, M., Bøegh-Petersen, J., Bredie, W. L. P., & Frøst, M. B. (2014). Stimulus collative properties and consumers' flavor preferences. *Appetite*, *77*, 20–30. https://doi.org/10.1016/j.appet.2014.02.007

Haws, K. L., & Winterich, K. P. (2013). When value trumps health in a supersized world. *Journal of Marketing*, *77*(3), 48–64. https://doi.org/10.1509/jm.11.0261

Hyde, R. J., & Witherly, S. A. (1993). Dynamic contrast: a sensory contribution to palatability. *Appetite*, *21*(1), 1–16. https://doi.org/10.1006/appe.1993.1032

Lähteenmäki, L., & Van Trijp, H. C. M. (1995). Hedonic responses, variety-seeking tendency and expressed variety in sandwich choices. *Appetite*, *24*(2), 139–151. https://doi.org/10.1016/S0195-6663(95)99358-4

Lenglet, F. (2018). FNS or the Varseek-scale? Proposals for a valid operationalization of neophilia. *Food Quality and Preference*, *66*, 76–84. https://doi.org/10.1016/j.foodqual.2018.01.007

Levitsky, D. A., Iyer, S., & Pacanowski, C. R. (2012). Number of foods available at a meal determines the amount consumed. *Eating Behaviors*, *13*(3), 183–187. https://doi.org/10.1016/j.eatbeh.2012.01.006

Lévy, C. M., MacRae, A., & Köster, E. P. (2006). Perceived stimulus complexity and food preference development. *Acta Psychologica*, *123*(3), 394–413. https://doi.org/10.1016/j.actpsy.2006.06.006

Marcano, J., Morales, D., Vélez-ruiz, J. F., & Fiszman, S. (2015). Does food complexity have a role in eliciting expectations of satiating capacity? *Food Research International*, *75*, 225–232. https://doi.org/10.1016/j.foodres.2015.06.012

Mielby, L. H., Kildegaard, H., Gabrielsen, G., Edelenbos, M., & Thybo, A. K. (2012). Adolescent and adult visual preferences for pictures of fruit and vegetable mixes – effect of complexity. *Food Quality and Preference*, *26*(2), 188–195. https://doi.org/10.1016/j.foodqual.2012.04.014

Palczak, J., Blumenthal, D., Rogeaux, M., & Delarue, J. (2019). Sensory complexity and its influence on hedonic responses: a systematic review of applications in food and beverages. *Food Quality and Preference*, *71*, 66–75. https://doi.org/10.1016/j.foodqual.2018.06.002

Palczak, J., Giboreau, A., Rogeaux, M., & Delarue, J. (2020). How do pastry and culinary chefs design sensory complexity? *International Journal of Gastronomy and Food Science*, *19*, 100182. https://doi.org/10.1016/j.ijgfs.2019.100182

Parizel, O., Labouré, H., Marsset-Baglieri, A., Fromentin, G., & Sulmont-Rossé, C. (2017). Providing choice and/or variety during a meal: impact on vegetable liking and intake. *Appetite*, *108*, 391–398. https://doi.org/10.1016/j.appet.2016.10.027

Polivy, J., Herman, C. P., & Mills, J. S. (2020). What is restrained eating and how do we identify it? *Appetite*, *155*, 104820. https://doi.org/10.1016/j.appet.2020.104820

Porcherot, C., & Issanchou, S. (1998). Dynamics of liking for flavoured crackers: test of predictive value of a boredom test. *Food Quality and Preference*, *9*(1–2), 21–29. https://doi.org/10.1016/S0950-3293(97)00023-2

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Raynor, H. A., & Vadiveloo, M. (2018). Understanding the relationship between food variety, food intake, and energy balance. *Current Obesity Reports, 7,* 68–75. https://doi.org/10.1007/s13679-018-0298-7

Reily, N. M., & Vartanian, L. R. (2016). The portion size effect on food intake is robust to contextual size information. *Appetite*, *105*, 439–448. https://doi.org/10.1016/j.appet.2016.06.015

Robinson, E., & Kersbergen, I. (2018). Portion size and later food intake: evidence on the "normalizing" effect of reducing food portion sizes. *The American Journal of Clinical Nutrition*, *107*(4), 640–646. https://doi.org/10.1093/ajcn/nqy013

Rolls, B. J. (2014). What is the role of portion control in weight management? *International Journal of Obesity*, *38*, S1–S8. https://doi.org/10.1038/ijo.2014.82

Rolls, B. J., Rolls, E. T., Rowe, E. A., & Sweeney, K. (1981). Sensory specific satiety in man. *Physiology & Behavior*, *27*(1), 137–142. https://doi.org/10.1016/0031-9384(81)90310-3

Rolls, B. J., Rowe, E. A., Rolls, E. T., Kingston, B., Megson, A., & Gunary, R. (1981). Variety in a meal enhances food intake in man. *Physiology & Behavior*, *26*(2), 215–221. https://doi.org/10.1016/0031-9384(81)90014-7

Rozin, P., Kabnick, K., Pete, E., Fischler, C., & Shields, C. (2003). The ecology of eating: smaller portion sizes in France than in the United States help explain the French paradox. *Psychological Science*, *14*(5), 450–454.

RStudio Team (2021). RStudio: Integrated Development Environment for R. RStudio, PBC, Boston, MA. URL http://www.rstudio.com/.

Sawtooth Software (n.d.). Choice-based conjoint. Retrieved from https://sawtoothsoftware.com/conjoint-analysis/cbc. Accessed 6 May 2021.

Soerensen, J. G., Waehrens, S. S., & Byrne, D. V. (2015). Predicting and understanding long-term consumer liking of standard versus novel chocolate: a repeated exposure study. *Journal of Sensory Studies*, *30*(5), 370–380. https://doi.org/10.1111/joss.12164

Spence, C. (2018). Complexity on the menu and in the meal. *Foods*, *7*(10), 158. https://doi.org/10.3390/foods7100158

Spence, C., & Wang, Q. J. (2018). On the meaning(s) of perceived complexity in the chemical senses. *Chemical Senses*, *43*(7), 451–461. https://doi.org/10.1093/chemse/bjy047

Steenhuis, I. H. M., Leeuwis, F. H., & Vermeer, W. M. (2009). Small, medium, large or supersize: trends in food portion sizes in The Netherlands. *Public Health Nutrition*, *13*(6), 852–857. https://doi.org/10.1017/S1368980009992011

Steenhuis, I., & Poelman, M. (2017). Portion size: latest developments and interventions. *Current Obesity Reports*, *6*, 10–17. https://doi.org/10.1007/s13679-017-0239-x

Stolzenbach, S., Bredie, W. L. P., Christensen, R. H. B., & Byrne, D. V. (2016). Understanding liking in relation to sensory characteristics, consumer concept associations, arousal potential and "appropriateness for use" using apple juice as an application. *Journal of Sensory Studies*, *31*(2), 135–142. https://doi.org/10.1111/joss.12200

Vabø, M., & Hansen, H. (2014). The relationship between food preferences and food choice: a theoretical discussion. *International Journal of Business and Social Science*, *5*(7), 145–157.

van Strien, T., Frijters, J. E. R., Bergers, G. P. A., & Defares, P. B. (1986). The Dutch eating behavior questionnaire (DEBQ) for assessment of restrained, emotional, and external eating behavior. *International Journal of Eating Disorders*, *5*(2), 295–315. https://doi.org/10.1002/1098-108X(198602)5:2<295::AID-EAT2260050209>3.0.CO;2-T

van Trijp, H. C. M., & Steenkamp, J. E. M. (1992). Consumers' variety seeking tendency with respect to foods: measurement and managerial implications. *European Review of Agricultural Economics*, *19*(2), 181–195. https://doi.org/10.1093/erae/19.2.181

Van Wymelbeke, V., Sulmont-Rossé, C., Feyen, V., Issanchou, S., Manckoundia, P., & Maître, I. (2020). Optimizing sensory quality and variety: an effective strategy for increasing meal enjoyment and food intake in older nursing home residents. *Appetite*, *153*, 104749. https://doi.org/10.1016/j.appet.2020.104749

Vermeer, W. M., Steenhuis, I. H. M., & Seidell, J. C. (2010). Portion size: a qualitative study of consumers' attitudes toward point-of-purchase interventions aimed at portion size. *Health Education Research*, *25*(1), 109–120. https://doi.org/10.1093/her/cyp051

Weijzen, P. L. G., Zandstra, E. H., Alfieri, C., & De Graaf, C. (2008). Effects of complexity and intensity on sensory specific satiety and food acceptance after repeated consumption. *Food Quality and Preference*, *19*(4), 349–359. https://doi.org/10.1016/j.foodqual.2007.11.003

Wijnhoven, H. A. H., van der Meij, B. S., & Visser, M. (2015). Variety within a cooked meal increases meal energy intake in older women with a poor appetite. *Appetite*, *95*, 571–576. https://doi.org/10.1016/j.appet.2015.08.029

Wilkinson, L. L., Hinton, E. C., Fay, S. H., Rogers, P. J., & Brunstrom, J. M. (2013). The 'variety effect' is anticipated in meal planning. *Appetite, 60*, 175–179. https://doi.org/10.1016/j.appet.2012.10.001

Young, L. R., & Nestle, M. (2002). The contribution of expanding portion sizes to the US obesity epidemic. *American Journal of Public Health*, *92*(2), 246–249. https://doi.org/10.2105/AJPH.92.2.246

Young, L. R., & Nestle, M. (2007). Portion sizes and obesity: responses of fast-food companies. *Journal of Public Health Policy*, *28*, 238–248. https://doi.org/10.1057/palgrave.jphp.3200127

Young, L. R., & Nestle, M. (2012). Reducing portion sizes to prevent obesity: a call to action. *American Journal of Preventive Medicine*, *43*(5), 565–568. https://doi.org/10.1016/j.amepre.2012.07.024

Zuraikat, F. M., Smethers, A. D., & Rolls, B. J. (2019). The influence of portion size on eating and drinking. In H. L. Meiselman (Ed.), *Handbook of Eating and Drinking* (pp. 2–28). Springer, Cham. https://doi.org/https://doi.org/10.1007/978-3-319-75388-1_129-1

6
General discussion

The aim of this dissertation was to further the understanding of sensory-specific satiation (SSS) and the variety effect. More specifically, the studies in this dissertation addressed whether: SSS and the variety effect are truly two sides of the same coin (**Chapter 2**); SSS is context-dependent (**Chapter 3**); top-down cognitive processes influence SSS (**Chapter 4**); SSS and the variety effect are important for food selection (**Chapter 5**). In this chapter, the results of these studies are summarized, the theoretical and practical implications are discussed, and remaining questions are identified. Suggestions and recommendations for future research are given throughout the chapter.

Main findings

The study described in **Chapter 2** investigated the presumed relationship between SSS and the variety effect. Participants consumed a high- and low variety meal consisting of 10 bite sized food portions; the low-variety meal consisted of 5 portions of cheese and 5 portions of sausage; the high variety meal consisted of 5 portions of cheese and 1 portion of sausage, toast with egg salad, toast with chicken curry salad, walnut, and meatball. Before and after consuming the meal, the participants rated their liking of and desire to eat the foods included in the meals and two additional control foods. SSS (in terms of liking) developed to the same degree for cheese in both meal varieties. For sausage, SSS was only present for the low variety meal (5 portions of sausage). These results show that SSS is primarily determined by the amount of orosensory exposure to a food. This indicates that variety affects SSS directly by diminishing exposure, and not by the experience of eating a different food within the meal.

Chapter 3 reported a study replicating SSS and the variety effect in a large group of participants, and additionally investigating whether a context-switch affects food intake (indicative of context-dependence of SSS). In that study, participants first evaluated their liking of and desire to eat eight foods, then consumed one of these eight foods ad libitum, after which they re-evaluated the eight foods. After that second round of evaluating the eight foods, they were served a second course consisting of either the same food as in the first course or a different food, served in either the same or a different room (a context-switch). Participants in the study demonstrated SSS after the first course and ate more of the second course when served a different food (the variety effect). Serving the food in a different room did not affect food intake, which suggests that SSS is not context-specific.

In **Chapter 4,** we studied the influence of cognition on food intake and SSS. Participants ate lunch (a pasta salad) ad libitum on two occasions. They were told that this pasta salad was ‘filling’ on one occasion and that it was ‘light’ on the other occasion. In reality, the pasta salads the participants ate were identical. We measured food intake and the development of SSS using the standard SSS test protocol (i.e., tasting and evaluating the pasta salad and seven control foods before and after consumption of the pasta salad). Food intake was significantly increased when the pasta salad was described as a ‘light’ meal, compared to when it was described as ‘filling’, while the magnitude of

SSS was equal. In other words, the participants ate more of the 'light' meal for a similar (relative) change in liking. However, when the magnitude of SSS was corrected for the amount consumed, no effect of the label on SSS was present. Participant's beliefs about the satiating capacity of the pasta salad affected consumption of the meal, but we found no clear evidence that the labels affected SSS.

We investigated the relevance of SSS and food variety for food preference in **Chapter 5**. In two online choice-based conjoint studies, we determined the importance of food variety in ice cream preference when compared to food complexity (Study 1), and portion size (Study 2). Dutch and American consumers were asked to choose their preferred option from a range of ice cream options ranging in level of complexity and variety (Study 1), and in variety and portion size (Study 2). Study 1 revealed that, cross-culturally, variety was more preferred than complexity, although ice cream options that were both varied and complex were the most popular. Study 2 showed that variety was preferred when choosing between different flavours, and that the flavour was more important than portion size. These preferences were the same for the American and Dutch participants. They did, however, differ regarding portion size preference; that is, American consumers preferred larger portions of ice cream than did Dutch consumers.

Methodological considerations

Limitations

Several limitations should be considered when interpreting the results of the studies in this dissertation. First, the participants in the studies described in **Chapter 2, 3, and 4** were (overall) healthy participants without any eating disorders, and mostly individuals with healthy weight or slight overweight. Therefore, the results of these studies cannot be generalized to populations with eating disorders and individuals with obesity. Additionally, the participants in the studies of **Chapters 2 and 3** were aged between 18 and 50 years and in the studies of **Chapters 4 and 5** between 18 and 65 years. Since individuals of older age (i.e., older than 65 years) are (presumably) less susceptible to SSS (Remick et al., 2009), the results cannot be generalized to older adults.

Second, all studies except for **Chapter 5** were conducted in a laboratory environment. Although this environment provides a controlled eating situation, the results need replication in naturalistic eating situations (see also Rogers et al., 2021). SSS is typically investigated in a laboratory environment in which participants are deprived from any distractions such as their phone, and are eating alone. However, in real life, people are often eating together and/or engaging in other activities (such as watching television), which has been found to affect SSS (see e.g., Braude & Stevenson, 2014). In a pilot study where we tested whether SSS could be influenced by the size of the tableware (which was conducted in a naturalistic setting), we experienced the difficulty to extrapolate laboratory findings to real life eating situations. Participants in that pilot study took part during a social event, and clearly influenced each other's intake, thereby confounding the results.

Clearly, more studies need to be conducted in naturalistic settings or in a more naturalistic set-up to gain better understanding of the external validity of SSS and the variety effect. For example, the study described in **Chapter 4** could be replicated in a more naturalistic design by letting participants self-serve the food accompanied by a label describing the satiating capacity. In this way the effect on pre-meal planning – which is affected by factors such as expected satiation and is likely to occur in many real-world eating situations (see e.g., Forde et al., 2015; Brunstrom, 2014) – can be incorporated into the design. Such studies would also provide a much better insight in the extent to which SSS and the variety effect can be manipulated to influence food choice and either stimulate or decrease food intake (as discussed below).

Recommendations

Four important methodological recommendations should be considered for future research investigating SSS and the variety effect. First, when investigating potential moderators of SSS, keeping the food intake constant can prevent the amount eaten to confound the effect of the moderator. Although ad libitum food intake resembles a more natural eating situation, the difference in food intake between conditions masks the influence of the moderator under study on SSS (see also **Chapter 4**).

Second, within-meal variety effects need to be distinguished from longer-term (across-meals or across days) variety effects. While the within-meal variety effect is presumably caused by SSS, monotony is more likely to be the mechanism responsible for long-term variety effects. The difference between SSS and monotony is, unfortunately, not well established. Monotony pertains to the decrease in liking of food due to repetition across meals, within 1 day up to several months (Siegel & Pilgrim, 1958; Remick et al., 2009). Note that in a standard monotony paradigm, decreased liking of the food under study is not compared to 'uneaten foods' (Remick et al., 2009). Some researchers have argued that SSS has 'long term effects' or have referred to monotony as 'long-term sensory-specific satiety' (see e.g., E. T. Rolls & De Waal, 1985; Chung & Vickers, 2007). SSS has also been suggested to affect product choice across days (e.g., Maier et al., 2007). However, studies have shown that SSS is a bad predictor of long-term food acceptability (Chung & Vickers, 2007; Weijzen et al., 2008; Vickers, 2017). In light of these conflicting findings and as B. J. Rolls (1986) has suggested, SSS and monotony do seem to be separate phenomena presumably with their own characteristics and origin; SSS is a rapid and short-lived effect occurring within a meal, while monotony extends beyond the meal.

Third, when investigating food variety, it should be clearly explained how variety is operationalized (see general introduction of this thesis; Raynor & Vadiveloo, 2018; Embling et al., 2021). For example, within-meal variety should be separated from meal complexity, since these are likely separate food characteristics (as indicated by **Chapter 5**). The operationalizations of complexity and variety as used in **Chapter 5** would be a useful starting point, as they clearly distinguish complexity as within-food characteristic from variety as between-food characteristic. Clearly defining food variety thus helps to avoid conflating different food characteristics that may have a differential impact on eating behaviour.

Fourth, although SSS is defined as the (relative) decrease in pleasantness of a food, in many SSS studies it is operationalized by a relative decrease in both subjective 'liking' and 'desire to eat' (just as we did in **Chapters 2, 3, and 4**). There has been much discussion on the separation of food liking and wanting (which may be represented by a 'desire to eat') in human food reward studies (Havermans, 2011; Finlayson & Dalton, 2012; Havermans, 2012; Havermans, Janssen, et al., 2009; Rogers & Hardman, 2015). Neurophysiological (animal) studies suggest that liking and wanting are regulated by separate neurological brain circuits (Morales & Berridge, 2020). There is evidence indicating that SSS reflects a decrease in both liking and wanting (i.e., desire to eat). However, 'desire to eat' often decreases more strongly than do liking ratings (as we also found in **Chapters 2, 3, and 4**; see also He et al., 2017; Rogers & Hardman, 2015), which suggests that wanting and liking are indeed different aspects of food reward. In natural eating situations they are likely to inform each other (Rogers & Hardman, 2015; Havermans, 2011; Morales & Berridge, 2020), and thus liking and wanting ratings will not readily dissociate. In SSS studies, participants have been found to experience difficulties to separate liking and wanting (Rogers et al., 2021; Hetherington & Rolls, 1996). Liking and wanting ratings, therefore, often overlap in self-report, but it is still useful to measure them both in SSS studies to capture the full subjective experience of hedonic motivation.

Further questions

Mechanisms underlying SSS: habituation or boredom?

In **Chapters 2 and 3** it was shortly discussed whether SSS reflects response habituation, which is one of the mechanisms that has been proposed to underlie SSS and the variety effect (see e.g., Hetherington & Havermans, 2013; Raynor & Vadiveloo, 2018; Raynor & Epstein, 2001; Piqueras-Fiszman & Spence, 2014). Response habituation was defined by Harris (1943, p. 385) as "response decrement as the result of repeated stimulation". In other words, when one is repeatedly presented with a specific stimulus, the response to that stimulus diminishes until it is completely absent (one has 'habituated' to the stimulus). Several key characteristics of habituation have been identified, which are presented in Box 2 (see Rankin et al., 2009; Hetherington & Havermans, 2013).

Hetherington and Havermans (2013) discussed whether SSS can be viewed as a form of response habituation. Their analysis led to the conclusion that SSS shares with habituation that: the response (i.e., liking of and the desire to eat a food) decreases with repeated orosensory exposure (characteristic 1); liking of and desire to eat a food recovers spontaneously over time when exposure has ended (characteristic 2); the decrease in responding can be delayed (characteristic 4); and the decrease in responding is stimulus specific (characteristic 7). However, contrary to habituation: SSS does not increase after frequent stimulation (characteristic 3); SSS does not seem to dishabituate (characteristic 8) (see also Meillon et al., 2013); and it is (probably) not sensitive to stimulus (food) intensity (characteristic 5).

Box 2. (Revised) characteristics of habituation, adapted from Rankin et al. (2009) and Hetherington and Havermans (2013).

Characteristics of habituation		
1.	**Decreased responding**	When a stimulus is presented repeatedly, the response to that stimulus decreases progressively, to an asymptotic level. Prior to this decrement, the response may increase due to sensitization.
2.	**Spontaneous recovery**	After response decrement, the response recovers at least partially when there is no exposure to the stimulus.
3.	**Potentiation of habituation**	The response decrement is more rapid and/or more pronounced after multiple series of stimulus presentations and (spontaneous) recovery.
4.	**Frequency effect**	More frequent stimulus presentation leads to a more rapid (and/or more pronounced) decrease in responding and a faster rate of spontaneous recovery (when the response has decreased to an asymptotic level).
5.	**Intensity effect**	Intensity of the stimulus affects habituation. With less intense stimuli, there is a more rapid and/or more pronounced response decrement, while presentation of very intense stimuli may not result in any observable decrease in responding.
6.	**Super habituation**	Habituation may continue to accumulate even after the response has reached asymptotic levels (not necessarily a complete response decrement), which can affect subsequent responding (e.g., delaying spontaneous recovery of responding).
7.	**Stimulus generalisation**	The response decrement is stimulus specific but can generalize to similar stimuli.
8.	**Dishabituation**	Presenting a different stimulus increases the (decremented) response to the original stimulus.
9.	**Habituation of dishabituation**	Repeated exposure to the (same) dishabituating stimulus attenuates dishabituation.
10.	**Long-term habituation**	Some aspects of habituation (e.g., more rapid rehabituation than baseline) can persist over time (e.g., lasting hours, days, or weeks).

As stated above, the operationally defining characteristic of habituation is response decrement. Habituation then is often described as a rudimentary form of learning. An organism learns through experience that a specific stimulus can be safely ignored (Rankin et al., 2009). SSS seems to reflect such a response decrement – it is characterized by a hedonic decline promoting meal termination. However, data from the study presented in **Chapter 2** suggest that hedonic valuation of the consumed test food does not simply decrease and shift toward a point of hedonic indifference, but typically changes from positive to negative valuation. In other words, ample exposure to a food within a relatively short period of time will lead to a dislike of that food. The initial desire to eat the food changes to a desire to not eat that food. Therefore, SSS represents a qualitative shift in responding to food, not a mere response decrement.

When participants are required to consume a fixed, pre-determined volume of food, chances are that some participants will consume more food than they otherwise would have when allowed to eat ad libitum. In naturalistic eating situations it is reasonable to expect that one usually terminates a meal when one no longer derives much pleasure from it (see B. J. Rolls et al., 1981). Nonetheless, it is conceivable that in certain situations one might eat a meal to the point of revulsion, especially when one feels compelled to plate clearing. But whether a strong food dislike with its consumption is a likely occurrence in real life is irrelevant. The suggestion that it happens in participants within the context of a food science experiment, simply does not align with the operational definition of habituation. But if not habituation, then what other general mechanism can explain SSS?

Hetherington and Havermans (2013) argued that SSS might be a boredom-like effect more suitably aligned with Glanzer's (1953) 'stimulus satiation' or Anitra Karsten's (1928) 'psychische Sättigung'. Karsten directed her subjects to perform repetitive, monotonous tasks such as drawing lines or reciting the same poem over and over for hours on end. She keenly observed how performance on these tasks deteriorated with repetition. When reciting the same poem for hours, a subject would start to stutter. Subjects having to draw straight lines would start to feel compelled to create various patterns in which they drew their lines. Notably, Karsten mentions "Affektausbruchen" (emotional outbursts, anger mostly) that many of her subjects experienced during their repetitive tasks. These outbursts were often directed towards the task (and sometimes toward the experimenter). Especially when the repetitive task felt purposeless, psychological satiation would set in quickly, but when the task had meaning (e.g., when financial remuneration was offered) very little or no psychological satiation occurred.

Murray Glanzer coined the term 'stimulus satiation' (based on Karsten's work) to explain why rats that were placed in a T-maze 'spontaneously alternated' between the two alleys at the choice point: 'choose to enter the right alley' versus 'choose to enter the left alley'. He argued that the rats alternate choices between left and right alley because they are trying to prevent or diminish 'satiation' for either the left or right alley (the 'stimulus'). According to a stimulus satiation account, repeated presentation of a stimulus will result in 'boredom' with the stimulus (Glanzer, 1953), decreasing the response to the stimulus.

It still remains to be determined whether SSS indeed reflects a boredom-like effect like psychological satiation as described above (see also Zoon et al., 2018). To determine whether SSS resembles a 'boredom effect', one could investigate whether a person voluntarily performs an unpleasant (or even painful) behaviour to 'escape' from eating the same food over and over. In studies on boredom, participants have been found to self-administer unpleasant electrocutaneous shocks in an effort to handle boredom (see e.g., Havermans et al., 2015). So, for example, would participants eventually prefer to self-administer a painful electric shock above the consumption of yet another piece of the same food? Another less dramatic (and less ethically dubious) suggestion for a study could be offering participants a choice after having eaten a specific food ad libitum until pleasantly full (i.e., SSS is established). The choice then is between having to eat a second serving of food (as much in weight and calories as the first serving), or a smaller serving depending on one's performance on a series of extremely challenging (unsolvable) mental puzzles. The participant is told that the amount of food that needs to be consumed in the second serving diminishes with each puzzle that is solved. The second serving is either a different food, or the same food as in the first serving. I hypothesize that the prospect of having to eat the same amount of the same food again is highly unpleasant and thus motivates participants to limit intake (i.e., the desire to not eat), but only when this second serving is the same food as before. The increased food-avoidance-motivation would not only be apparent in the willingness to try solving the puzzles but also reflected by the time devoted to these unsolvable puzzles. Such a finding would be evidence supporting what Anitra Karsten described with the very German term "Wegrennenwollen" (wanting-to-run-away).

How much variety is needed for a variety effect?

Anitra Karsten (1928) noted how psychological satiation seemed to increase the desire for variation, or rather, the urge for a change in stimulation. This observation may be interpreted as being similar to the variety effect, where the subject is able to consume more food because of the variety of food that is being offered, thus allowing the subject to limit the development of SSS. Food variety appeals to the consumer (see also **Chapter 5**). But what counts as food or meal variety? When are foods to be notably different as to count as variety? It is an important question as a better understanding of the extent to which foods need to be dissimilar to prevent SSS from generalization provides valuable information for designing healthy, palatable meals in which healthy foods can be combined in a way to maintain appetite (i.e., attenuating SSS).

Many researchers have reported that SSS generalizes to sensorially similar foods (e.g., Vickers, 2017; Maier et al., 2007; Nolan & Hetherington, 2009; Olsen et al., 2011). In numerous SSS studies, the decrease in liking for an eaten food seems to transfer to foods that share sensory features (see e.g., Meillon et al., 2013; Havermans, Geschwind, et al., 2009; Rogers et al., 2020; B. J. Rolls et al., 1982, Experiment 3; B. J. Rolls et al., 1981). But in some studies, no such transfer was found (see e.g., Romer et al., 2006; Griffioen-Roose et al., 2010). For example, in two studies conducted by Weijzen et al. (2008), the relative decrease in liking for a consumed soup was not different from uneaten soups that were similar, suggesting transfer of SSS. But for three out of four sweet snacks (chocolate, candy bar with chocolate and nuts, tea biscuit, and wholemeal biscuit with chocolate), the relative decrease in liking for the eaten snack did differ from the other three (uneaten) snacks – suggesting little transfer of SSS. In the study described in **Chapter 3**, we too did not observe transfer of SSS to any of the uneaten foods sharing textural, taste, or visual characteristics (see exploratory results on The Open Science Framework: https://osf.io/hu3pg/).

If SSS is indeed a mechanism (as proposed) that encourages eating different nutrients of which its presence in food is signalled by sensory qualities (see e.g., Boesveldt & De Graaf, 2017; De Graaf, 2012; B. J. Rolls et al., 1981), it makes sense that SSS transfers to sensorially similar foods. But clearly, such transfer does not always occur. It remains to be determined, then, to what extent unconsumed foods need to be similar to the consumed food for SSS to generalize to these foods (see e.g., Guinard et al., 2002). More importantly, when considering the application of the variety effect to promote intake of certain foods or meals in certain individuals (e.g., to increase intake of protein rich foods in older individuals to prevent or reduce sarcopenia), it is pertinent to better understand when and how food variety may limit SSS and hence promote intake.

Is the gastrointestinal tract a chemosensory organ?

SSS is typically viewed as the result from orosensory exposure to food. That orosensory exposure comprises mouthfeel, retronasal smell, and taste sensations. Umami, bitter, and sweet taste sensations are mediated by G-protein coupled receptors (GPCR) (San Gabriel, 2015). These taste receptor cells are clustered in taste buds lining the gustatory papillae on the tongue and palate (Depoortere, 2014). These GPCRs have, however, also been found in the gastrointestinal (GI) tract (oesophagus, stomach, and intestines; see e.g., Depoortere, 2014; De Araujo et al., 2012; San Gabriel, 2015; Keast et al., 2021).

Since SSS depends on sensory exposure (it is not affected by macronutrient composition or energy density), one could speculate that there is a post-oral role for taste receptor cells present in the GI tract, where GPCRs are thought to be involved in tastant/nutrient sensing allowing for modulation of digestion and metabolism (San Gabriel, 2015). In line with this reasoning, SSS seems to be strongest when foods are actually ingested as opposed to only sham-fed or smelled (see e.g., Romer et al., 2006; E. T. Rolls & J. H. Rolls, 1997; Smeets & Westerterp-Plantenga, 2006; Raynor & Epstein, 2001). The involvement of intestinal GPCRs in the lower GI tract might also explain why recovery from SSS is not immediate with meal termination (see e.g., Hetherington & Havermans, 2013). Stimulation of taste receptors along the GI tract could signal the brain in a similar way that taste receptors in the mouth signal the ‘arrival’ of nutrients. Indeed, vagal afferents from the GI tract synapse in the nucleus of the solitary tract, from which it projects to the amygdala and hypothalamus (San Gabriel, 2015), just like orosensory signals (Lasschuijt et al., 2021). Moreover, post-oral delivery of non-caloric tastants (i.e., quinine-hydrochloride in the stomach) has been found to increase activity in brain regions involved in hedonic motivation (including SSS): the anterior insula, amygdala, and orbitofrontal cortex (see Iven et al., 2019; E. T. Rolls, 2021).

It has been suggested that sensing of non-caloric tastants in the GI tract contributes to satiation and satiety. A recent systematic review of studies examining this potential appetite and energy intake effect of post-oral delivery of tastants shows that studies are still relatively scarce and that findings are mixed (Klaassen et al., 2021). It is still largely unclear which tastants should be delivered in what dose, and where in the GI tract, to have a meaningful impact on satiation and satiety. More research is needed here and it would be interesting to include a measure for SSS in these future investigations. For example, intragastric infusion of a bitter, sweet or umami tastant could be paired with consumption of a test food matched in taste, or participants could be asked to taste and evaluate a range of taste-matched and taste-unmatched foods before and after intragastric infusion of a non-caloric tastant.

If post-oral taste receptors can indeed contribute to SSS in a similar way as the oral taste system, then SSS and negative alliesthesia as proposed by Cabanac (1971) might be related mechanisms originating from different digestive phases; SSS originating from the oral sensory system, alliesthesia from the post-oral sensory system. In line with this idea, Cabanac and Fantino (1977) found that Mannitol (a sugar alcohol that is poorly absorbed) produced alliesthesia, implying that absorption is not necessary for negative alliesthesia to occur. Perhaps SSS and negative alliesthesia are similar mechanisms, simply originating in different locations within the digestive ‘system’.

Practical implications and future directions

SSS is thought to promote the consumption of a varied diet, and consequently, ensures nutrient adequate intake (B. J. Rolls et al., 1981; Davidson et al., 2018). Forty years of research has shown that SSS and the variety effect are indeed important determinants of food choice and intake. The insights gathered in these forty years – including the findings of the studies in this dissertation – can be used to develop appealing healthy meals and to encourage selection of healthy, nutritious foods. Below, I discuss examples of applying the principles of SSS to subtly influence (nudge if you will) food intake.

Moderating SSS by manipulating orosensory exposure

The study described in **Chapter 2** provides direct evidence that sensory exposure to food determines SSS and the effect of food variety on SSS. This insight provides an interesting starting point to investigate how SSS can be used to promote or limit food intake. If sensory exposure determines SSS, which in its turn affects meal termination, directly manipulating orosensory exposure to food should affect SSS, and thus, food intake (De Graaf, 2019; Robinson et al., 2014; Krop et al., 2018). Orosensory exposure can be affected by texture, bite size, and eating rate (see e.g., Robinson et al., 2014). For example, in a study by Hogenkamp et al. (2010), using a spoon to eat a liquid yogurt opposed to drinking it with a straw decreased eating rate (g/min) and affected intake of the yogurt (see also James et al., 2018).

In a pilot study (conducted in a naturalistic setting), we explored this idea by letting two groups of participants eat a fixed portion of a food (a piece of cake [‘vlaai’]). One group received a small and the other a large fork to eat the cake. We determined SSS by letting the participants evaluate the cake and two other foods (stroopwafel and grain crisps; a sweet and savoury food) before and after eating the cake. SSS was present when the change in liking for the cake was compared to the grain crisp, but not when compared to the stroopwafel (or both control foods combined). In other words, SSS generalized to the unconsumed sweet food. The magnitude of SSS was not affected by the size of the fork. It should be noted, though, that although the participants were requested to consume the entire portion, some did not because the participants influenced each other's consumption (when a participant complained that the portion was too big, other participants stopped eating the cake as well). Unfortunately, food leftovers could not be determined. This pilot study demonstrates the difficulty in translating laboratory findings to natural eating situations, but the fact that SSS was still present when comparing the sweet consumed food (cake) to the savoury control food emphasizes the robustness of SSS.

Naturally, eating rate (and hence, orosensory exposure) is not only influenced by adjusting the size of eating utensils, but also by instructions to eat slowly (Robinson et al., 2014), or by manipulations of food properties such as texture (Bolhuis & Forde, 2020). For example, more liquid foods have less satiating potential because they allow for fast consumption and thus provide relatively little orosensory exposure (see also general introduction of this thesis; Boesveldt & De Graaf, 2017). Bolhuis and Forde (p. 454) therefore recently concluded that "applying food structure modifications to direct consumption behaviour creates new opportunities to go beyond traditional compositional reformulation approaches that solely focus on reducing salt, sugar, fat or portion size". The effects of such strategies on SSS and food intake remain to be determined.

'Expected' SSS and variety: food liking and choice

Although SSS and the variety effect seem to operate largely outside of consciousness (a decrease in 'food appeal' is not often experienced as a reason to stop eating; see Cunningham et al., 2021), results of our studies in **Chapter 5** and of a study by Wilkinson et al. (2013) suggest that people are aware of these phenomena at least to some extent. Wilkinson and colleagues found evidence that the variety effect is anticipated when choosing portion sizes, and we demonstrated that food variety is an important driver of ice cream preference, more so than complexity and portion size. It makes sense to presume that variety is preferred over complex or 'simple' ice cream products because one expects variety to increase eating 'pleasure'. Variety may thus be applied to steer individual food choice.

Since our results of **Chapter 5** are specific to ice cream, more research is needed to determine whether the preference for variety as found in these online choice experiments generalizes to foods with different nutritional and sensory properties and with different roles in the human diet. For example, would variety be equally preferred in breakfast foods as in snacks? And would results be similar for a varied meal constituting of (healthy) energy-poor, nutrient-dense foods? Replicating the conducted studies on ice cream preference for a wider array of foods would provide valuable information to design attractive healthy products and meals. Additionally, replication is warranted in real-life choice situations to investigate whether the online choices indeed translate to actual behaviour.

Our ice cream studies could be easily replicated by letting participants choose from the ice cream options that we presented in our online choice-experiment (free of charge). To connect these preference patterns for variety to SSS, it would also be interesting to investigate directly whether intake of the chosen foods that are either varied, complex, or both would differ in development of SSS. The evidence gathered thus far indicates that complexity does not seem to affect SSS (see Remick et al., 2009) and that it is unlikely to influence the variety effect (see Embling et al., 2021), but a direct comparison of varied and complex foods has (to my knowledge) not yet been explored with regard to SSS.

Although the findings of our ice cream choice-experiments show promising results of the potential of food variety to steer food selection and intake, more research is needed about its role in food liking, preference and selection. Especially how these results translate to real-life choice situations, and their connection with SSS should be explored further, which will also answer the question whether SSS and the variety effect are indeed 'expected' or 'anticipated'.

Conclusion

Although SSS and the variety effect are well-established phenomena which provide promising avenues for 'consumption control', even after forty years of research, there is still much more to discover in both fundamental and applied sense. I feel there are two main issues that warrant further study: 1) examining whether SSS indeed represents a more general boredom-like effect; 2) designing and testing the behavioural impact of interventions aimed at either increasing or decreasing SSS in meal situations. The current studies included in this dissertation provide only a first attempt at tackling these issues. The results will hopefully spur further discussion and of course research on SSS, a phenomenon that has been studied extensively but is still not fully understood. A phenomenon that clearly affects eating behaviour but is rarely or poorly applied to direct consumption.

References

Boesveldt, S., & De Graaf, K. (2017). The differential role of smell and taste for eating behavior. *Perception*, *46*(3–4), 307–319. https://doi.org/10.1177/0301006616685576

Bolhuis, D. P., & Forde, C. G. (2020). Application of food texture to moderate oral processing behaviors and energy intake. *Trends in Food Science & Technology*, *106*, 445–456. https://doi.org/10.1016/j.tifs.2020.10.021

Braude, L., & Stevenson, R. J. (2014). Watching television while eating increases energy intake. Examining the mechanisms in female participants. *Appetite*, *76*, 9–16. https://doi.org/10.1016/j.appet.2014.01.005

Brunstrom, J. M. (2014). Mind over platter: pre-meal planning and the control of meal size in humans. *International Journal of Obesity*, *38*, 9–12. https://doi.org/10.1038/ijo.2014.83

Cabanac, M. (1971). Physiological role of pleasure. *Science*, *173*(4002), 1103–1107. https://doi.org/10.1126/science.173.4002.1103

Cabanac, M., & Fantino, M. (1977). Origin of olfacto-gustatory alliesthesia: intestinal sensitivity to carbohydrate concentration? *Physiology & Behavior*, *18*(6), 1039–1045. https://doi.org/10.1016/0031-9384(77)90009-9

Chung, S. J., & Vickers, Z. (2007). Influence of sweetness on the sensory-specific satiety and long-term acceptability of tea. *Food Quality and Preference*, *18*(2), 256–264. https://doi.org/10.1016/j.foodqual.2005.12.002

Cunningham, P. M., Roe, L. S., Hayes, J. E., Hetherington, M. M., Keller, K. L., & Rolls, B. J. (2021). Development and validation of the Reasons Individuals Stop Eating Questionnaire (RISE-Q): a novel tool to characterize satiation. *Appetite*, *161*, 105127. https://doi.org/10.1016/j.appet.2021.105127

Davidson, G. R., Giesbrecht, T., Thomas, A. M., & Kirkham, T. C. (2018). Pre- and postprandial variation in implicit attention to food images reflects appetite and sensory-specific satiety. *Appetite*, *125*, 24–31. https://doi.org/10.1016/j.appet.2018.01.028

De Araujo, I. E., Geha, P., & Small, D. M. (2012). Orosensory and homeostatic functions of the insular taste cortex. *Chemosensory Perception*, *5*, 64–79. https://doi.org/10.1007/s12078-012-9117-9

De Graaf, C. (2012). Texture and satiation: the role of oro-sensory exposure time. *Physiology & Behavior*, *107*(4), 496–501. https://doi.org/10.1016/j.physbeh.2012.05.008

De Graaf, K. (2019). Sensory responses in nutrition and energy balance: role of texture, taste, and smell in eating behavior. In H. Meiselman (Ed.), *Handbook of eating and drinking*. Springer, Cham. https://doi.org/10.1007/978-3-319-75388-1_117-1

Depoortere, I. (2014). Taste receptors of the gut: emerging roles in health and disease. *Gut*, *63*, 179–190. https://doi.org/10.1136/gutjnl-2013-305112

Embling, R., Pink, A. E., Gatzemeier, J., Price, M., Lee, M. D., & Wilkinson, L. L. (2021). Effect of food variety on intake of a meal: a systematic review and meta-analysis. *The American Journal of Clinical Nutrition*, *113*(3), 716–741. https://doi.org/10.1093/ajcn/nqaa352

Finlayson, G., & Dalton, M. (2012). Current progress in the assessment of ‘liking’ vs. ‘wanting’ food in human appetite. Comment on ‘‘You Say it’s Liking, I Say it’s Wanting...’’. On the difficulty of disentangling food reward in man.’ *Appetite*, *58*(1), 373–378. https://doi.org/10.1016/j.appet.2011.10.011

Forde, C. G., Almiron-Roig, E., & Brunstrom, J. M. (2015). Expected satiety: application to weight management and understanding energy selection in humans. *Current Obesity Reports*, *4*, 131–140. https://doi.org/10.1007/s13679-015-0144-0

Glanzer, M. (1953). Stimulus satiation: an explanation of spontaneous alternation and related phenomena. *Psychological Review*, *60*(4), 257–268. https://doi.org/10.1037/h0062718

Griffioen-Roose, S., Finlayson, G., Mars, M., Blundell, J. E., & De Graaf, C. (2010). Measuring food reward and the transfer effect of sensory specific satiety. *Appetite*, *55*(3), 648–655. https://doi.org/10.1016/j.appet.2010.09.018

Guinard, J. X., Caussin, J., Campo Arribas, M., & Meier, J. (2002). Effect of exposure to the aroma of a preload on subsequent intake of a food with the same aroma. *Journal of Sensory Studies*, *17*(4), 351–363. https://doi.org/10.1111/j.1745-459X.2002.tb00352.x

Harris, J. D. (1943). Habituatory response decrement in the intact organism. *Psychological Bulletin*, *40*(6), 385–422. https://doi.org/10.1037/h0053918

Havermans, R. C. (2011). "You Say it's Liking, I Say it's Wanting…''. On the difficulty of disentangling food reward in man. *Appetite*, *57*(1), 286–294. https://doi.org/10.1016/j.appet.2011.05.310

Havermans, R. C. (2012). How to tell where 'liking' ends and 'wanting' begins. *Appetite*, *58*(1), 252–255. https://doi.org/10.1016/j.appet.2011.10.013

Havermans, R. C., Geschwind, N., Filla, S., Nederkoorn, C., & Jansen, A. (2009). Sensory-specific satiety is unaffected by manipulations of flavour intensity. *Physiology & Behavior*, *97*(3–4), 327–333. https://doi.org/10.1016/j.physbeh.2009.02.030

Havermans, R. C., Janssen, T., Giesen, J. C. A. H., Roefs, A., & Jansen, A. (2009). Food liking, food wanting, and sensory-specific satiety. *Appetite*, *52*(1), 222–225. https://doi.org/10.1016/j.appet.2008.09.020

Havermans, R. C., Vancleef, L., Kalamatianos, A., & Nederkoorn, C. (2015). Eating and inflicting pain out of boredom. *Appetite*, *85*, 52-57. http://dx.doi.org/10.1016/j.appet.2014.11.007

He, W., Boesveldt, S., Delplanque, S., De Graaf, C., & de Wijk, R. A. (2017). Sensory-specific satiety: added insights from autonomic nervous system responses and facial expressions. *Physiology & Behavior*, *170*, 12–18. https://doi.org/10.1016/j.physbeh.2016.12.012

Hetherington, M., & Havermans, R. C. (2013). Sensory-specific satiation and satiety. In J. E. Blundell & F. Bellisle (Eds.), *Satiation, satiety and the control of food intake. Theory and practice* (pp. 253–269). Woodhead Publishing Ltd. https://doi.org/10.1533/9780857098719.4.253

Hetherington, M. M., & Rolls, B. J. (1996). Sensory-specific satiety: theoretical frameworks and central characteristics. In E. D. Capaldi (Ed.), *Why we eat what we eat: the psychology of eating.* (pp. 267–290). American Psychological Association. https://doi.org/10.1037/10291-010

Hogenkamp, P. S., Mars, M., Stafleu, A., & De Graaf, C. (2010). Intake during repeated exposure to low- and high-energy-dense yogurts by different means of consumption. *The American Journal of Clinical Nutrition*, *91*(4), 841–847. https://doi.org/10.3945/ajcn.2009.28360

Iven, J., Biesiekierski, J. R., Zhao, D., Deloose, E., O'Daly, O. G., Depoortere, I., Tack, J., & Van Oudenhove, L. (2019). Intragastric quinine administration decreases hedonic eating in healthy women through peptide-mediated gut-brain signaling mechanisms. *Nutritional Neuroscience*, *22*(12), 850-862. https://doi.org/10.1080/1028415X.2018.1457841

James, L. J., Maher, T., Biddle, J., & Broom, D. R. (2018). Eating with a smaller spoon decreases bite size, eating rate and ad libitum food intake in healthy young males. *British Journal of Nutrition*, *120*(7), 830–837. https://doi.org/10.1017/S0007114518002246

Karsten, A. (1928). Untersuchungen zur handlungs- und affektpsychologie. *Psychologische Forschung*, *10*, 142–254. https://doi.org/10.1007/bf00492011

Keast, R., Costanzo, A., & Hartley, I. (2021). Macronutrient sensing in the oral cavity and gastrointestinal tract: alimentary tastes. *Nutrients*, *13*(2), 667. https://doi.org/10.3390/nu13020667

Klaassen, T., Keszthelyi, D., Troost, F. J., Bast, A., & Masclee, A. A. M. (2021). Effects of gastrointestinal delivery of non-caloric tastants on energy intake: a systematic review and meta-analysis. *European Journal of Nutrition*, *60*, 2923–2947. https://doi.org/10.1007/s00394-021-02485-4

Krop, E. M., Hetherington, M. M., Nekitsing, C., Miquel, S., Postelnicu, L., & Sarkar, A. (2018). Influence of oral processing on appetite and food intake – a systematic review and meta-analysis. *Appetite*, *125*, 253–269. https://doi.org/10.1016/j.appet.2018.01.018

Lasschuijt, M. P., De Graaf, K., & Mars, M. (2021). Effects of oro-sensory exposure on satiation and underlying neurophysiological mechanisms — what do we know so far? *Nutrients*, *13*(5), 1391. https://doi.org/10.3390/nu13051391

Maier, A., Vickers, Z., & Inman, J. J. (2007). Sensory-specific satiety, its crossovers, and subsequent choice of potato chip flavors. *Appetite*, *49*(2), 419–428. https://doi.org/10.1016/j.appet.2007.02.006

Meillon, S., Thomas, A., Havermans, R., Pénicaud, L., & Brondel, L. (2013). Sensory-specific satiety for a food is unaffected by the ad libitum intake of other foods during a meal: is SSS subject to dishabituation? *Appetite*, *63*, 112–118. https://doi.org/10.1016/j.appet.2012.12.004

Morales, I., & Berridge, K. C. (2020). 'Liking' and 'wanting' in eating and food reward: brain mechanisms and clinical implications. *Physiology & Behavior*, *227*, 113152. https://doi.org/10.1016/j.physbeh.2020.113152

Nolan, L. J., & Hetherington, M. M. (2009). The effects of sham feeding-induced sensory specific satiation and food variety on subsequent food intake in humans. *Appetite*, *52*(3), 720–725. https://doi.org/10.1016/j.appet.2009.03.012

Olsen, A., Ritz, C., Hartvig, D. L., & Møller, P. (2011). Comparison of sensory specific satiety and sensory specific desires to eat in children and adults. *Appetite*, *57*(1), 6–13. https://doi.org/10.1016/j.appet.2011.03.009

Piqueras-Fiszman, B., & Spence, C. (2014). Colour, pleasantness, and consumption behaviour within a meal. *Appetite*, *75*, 165–172. https://doi.org/10.1016/j.appet.2014.01.004

Rankin, C. H., Abrams, T., Barry, R. J., Bhatnagar, S., Clayton, D. F., Colombo, J., Coppola, G., Geyer, M. A., Glanzman, D. L., Marsland, S., Mcsweeney, F. K., Wilson, D. A., Wu, C., & Thompson, R. F. (2009). Habituation revisited: an updated and revised description of the behavioral characteristics of habituation. *Neurobiology of Learning and Memory*, *92*(2), 135–138. https://doi.org/10.1016/j.nlm.2008.09.012

Raynor, H. A., & Epstein, L. H. (2001). Dietary variety, energy regulation, and obesity. *Psychological Bulletin*, *127*(3), 325–341. https://doi.org/10.1037/0033-2909.127.3.325

Raynor, H. A., & Vadiveloo, M. (2018). Understanding the relationship between food variety, food intake, and energy balance. *Current Obesity Reports*, *7*, 68–75. https://doi.org/10.1007/s13679-018-0298-7

Remick, A. K., Polivy, J., & Pliner, P. (2009). Internal and external moderators of the effect of variety on food intake. *Psychological Bulletin*, *135*(3), 434–451. https://doi.org/10.1037/a0015327

Robinson, E., Almiron-Roig, E., Rutters, F., De Graaf, C., Forde, C. G., Smith, C. T., Nolan, S. J., & Jebb, S. A. (2014). A systematic review and meta-analysis examining the effect of eating rate on energy intake and hunger. *The American Journal of Clinical Nutrition*, *100*(1), 123–151. https://doi.org/10.3945/ajcn.113.081745

Rogers, P. J., Drumgoole, F. D. Y., Quinlan, E., & Thompson, Y. (2021). An analysis of sensory-specific satiation: food liking, food wanting, and the effects of distraction. *Learning and Motivation*, *73*, 101688. https://doi.org/10.1016/j.lmot.2020.101688

Rogers, P. J., Ferriday, D., Irani, B., Hoi, J. K. H., England, C. Y., Bajwa, K. K., & Gough, T. (2020). Sweet satiation: acute effects of consumption of sweet drinks on appetite for and intake of sweet and non-sweet foods. *Appetite*, *149*, 104631. https://doi.org/10.1016/j.appet.2020.104631

Rogers, P. J., & Hardman, C. A. (2015). Food reward. What it is and how to measure it. *Appetite*, *90*, 1–15. https://doi.org/10.1016/j.appet.2015.02.032

Rolls, B. J. (1986). Sensory-specific satiety. *Nutrition Reviews*, *44*(3), 93–101. https://doi.org/10.1111/j.1753-4887.1986.tb07593.x

Rolls, E. T. (2021). The orbitofrontal cortex, food reward, body weight and obesity. *Social Cognitive and Affective Neuroscience*, *00*(00), 1–19. https://doi.org/10.1093/scan/nsab044

Rolls, E. T., & De Waal, A. W. L. (1985). Long-term sensory-specific satiety: evidence from an Ethiopian refugee camp. *Physiology & Behavior*, *34*(6), 1017–1020. https://doi.org/10.1016/0031-9384(85)90032-0

Rolls, E. T., & Rolls, J. H. (1997). Olfactory sensory-specific satiety in humans. *Physiology & Behavior*, *61*(3), 461–473. https://doi.org/10.1016/S0031-9384(96)00464-7

Rolls, B. J., Rolls, E. T., Rowe, E. A., & Sweeney, K. (1981). Sensory specific satiety in man. *Physiology & Behavior*, *27*(1), 137–142. https://doi.org/10.1016/0031-9384(81)90310-3

Rolls, B. J., Rowe, E. A., & Rolls, E. T. (1982). How sensory properties of foods affect human feeding behavior. *Physiology & Behavior*, *29*(3), 409–417. https://doi.org/10.1016/0031-9384(82)90259-1

Romer, M., Lehrner, J., Van Wymelbeke, V., Jiang, T., Deecke, L., & Brondel, L. (2006). Does modification of olfacto-gustatory stimulation diminish sensory-specific satiety in humans? *Physiology & Behavior*, *87*(3), 469–477. https://doi.org/10.1016/j.physbeh.2005.11.015

San Gabriel, A. M. (2015). Taste receptors in the gastrointestinal system. *Flavour*, *4*, 14. https://doi.org/10.1186/2044-7248-4-14

Siegel, P. S., & Pilgrim, F. J. (1958). The effect of monotony on the acceptance of food. *The American Journal of Psychology*, *71*(4), 756–759. https://doi.org/10.2307/1420336

Smeets, A. J. P. G., & Westerterp-Plantenga, M. S. (2006). Oral exposure and sensory-specific satiety. *Physiology & Behavior*, *89*(2), 281–286. https://doi.org/10.1016/j.physbeh.2006.06.011

Vickers, Z. (2017). Satiety and liking intertwined. In B. Tepper & M. Yeomans (Eds.), *Flavor, Satiety and Food Intake* (First Edit, pp. 13–34). John Wiley & Sons Ltd. https://doi.org/10.1002/9781119044970.ch2

Weijzen, P. L. G., Zandstra, E. H., Alfieri, C., & De Graaf, C. (2008). Effects of complexity and intensity on sensory specific satiety and food acceptance after repeated consumption. *Food Quality and Preference*, *19*(4), 349–359. https://doi.org/10.1016/j.foodqual.2007.11.003

Wilkinson, L. L., Hinton, E. C., Fay, S. H., Rogers, P. J., & Brunstrom, J. M. (2013). The 'variety effect' is anticipated in meal planning. *Appetite*, *60*, 175–179. https://doi.org/10.1016/j.appet.2012.10.001

Zoon, H. F. A., Ohla, K., De Graaf, C., & Boesveldt, S. (2018). Modulation of event-related potentials to food cues upon sensory-specific satiety. *Physiology & Behavior*, *196*, 126–134. https://doi.org/10.1016/j.physbeh.2018.08.020

A

Appendices

Summary
Samenvatting
Impact addendum
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Summary

Forty years ago (in 1981), two papers were published in the scientific journal Physiology & Behavior, describing a number of experiments on 'sensory-specific satiation' and 'the variety effect', two important determinants of eating behaviour. Sensory specific-satiation (SSS) entails that when you eat a food, the pleasantness of that food declines, while foods that you did not eat remain equally pleasant. SSS thus affects how much you eat of a food. You stop eating once you derive no further pleasure from its consumption. In the 1981 experiments, the authors also observed a related effect to SSS. When they offered participants a greater variety of foods to eat, the participants ate more than study participants who could only eat from one food. This was termed 'the variety effect' and was presumed to be related to SSS. When the pleasantness of the food you are eating has declined so much that you stop eating, the opportunity to eat a different food (which is still liked) will make you resume eating.

The standard research paradigm to test SSS is to ask study participants to taste and evaluate a number of foods, after which they are offered one of those foods to eat (a fixed portion or as much as they would like). After they have finished eating that food, they repeat the evaluation of the foods they tasted before. SSS is expressed as the difference between the change in pleasantness of the eaten food and that of the unconsumed foods. To test for the variety effect, study participants receive either one food or a variety of foods to eat ad libitum (eat until pleasantly full). Alternatively, a variety effect is evident when participants eat more from a food that is different from the food they ate just before relative to the consumption of the same food. As introduced in **Chapter 1**, the aim of this dissertation was to improve our understanding of how SSS and the variety effect relate to each other, what factors can influence them, and whether they play a role in food choice.

In **Chapter 2**, a study is discussed in which the relationship between SSS and the variety effect is explored. We investigated the presumed mechanism between SSS and the variety effect. Study participants consumed a 'meal' low or high in variety. The low variety meal consisted of 5 bite sized portions of food A and B (A-B-A-B-A-B-A-B-A-B), while the high variety meal consisted of 5 bite sized portions of food A and one portion of food B, C, D, E, and F (A-B-A-C-A-D-A-E-A-F). The meals were consumed using a signalled exposure procedure (look-smell-taste-swallow). Before and after the meal, the participants tasted and evaluated the six foods that were included in the meals, and two unconsumed foods, to test SSS for food A and B. The magnitude of SSS for food A was equal in both meals, but for food B, SSS was only present when five portions were consumed (low variety meal). These results indicate that food variety affects SSS by diminishing exposure to the food.

Next, in **Chapter 3**, we investigated whether the eating context is important for SSS. Study participants tasted and evaluated eight foods, after which they ate one of those foods until they felt pleasantly full. Next, they again evaluated the same eight foods. After that second evaluation, they were offered either the same food to eat again, or a different food. One group of participants received this second 'course' in the same room, and another group received this second course in a different room (a context

A

switch). The results of this study showed that the participants developed SSS for the food they ate in the first course and ate more of the second course when this was a different food (the variety effect). Changing the room in which the food was served did not affect food intake, suggesting that SSS cannot be neutralized by simply changing the eating context. In other words, SSS does not seem to depend on the eating context.

Chapter 4 describes a study investigating the influence of cognitive cues on food intake and SSS. Specifically, we investigated the effect of food labels denoting the satiating power of a meal on consumption of that meal and the magnitude of SSS for the meal. Study participants consumed a pasta salad on two occasions. They were once told this was a 'filling' meal, and on the other occasion that it was a 'light' meal. In reality, the pasta salads were identical. The participants could eat freely from the meal until they felt pleasantly full. Before and after eating the pasta salad, they tasted and evaluated the pasta salad and seven other foods, to measure SSS. We found that the participants ate more of the pasta salad when it was labelled as 'light' than when it was labelled as 'filling'. Surprisingly, the magnitude of SSS they experienced was equal between label conditions, despite the difference in intake. However, when we corrected the magnitude of SSS for the amount of food consumed, we still did not find any differences between the label conditions. In other words, participants' consumption of the pasta salad was affected by the labels, but there was no clear evidence that the labels affected SSS.

Chapter 5 describes two studies investigating the relative importance of food variety for food choice. In two online choice-experiments we explored the relative importance of variety, complexity, and portion size for ice cream preferences in separate panels of Dutch and American consumers. In Study 1, we asked participants to choose their preferred ice cream from options ranging in level of variety and complexity. In Study 2, the ice cream options ranged in level of variety and in portion size. Both studies showed that variety was important for ice cream preference. In Study 1, variety was preferred over complexity (but ice cream that was both varied and complex was the most popular). In Study 2, the flavour of the ice cream was more important than the portion size, and when choosing between flavours, a variety of flavours was preferred. These results were found both for the Dutch and the American consumers. The only difference found between the two countries was the portion size preference; American consumers preferred larger portion sizes than did Dutch consumers. In sum, these two online choice-experiments indicate that food variety is a key determinant of food choice.

To recapitulate, the current dissertation reinforces the contention that SSS plays an important role in food intake and food choice. But, as I argue in **Chapter 6**, after four decades of research on SSS, several key questions remain. Firstly, it is unclear what general psychological mechanism underlies SSS. I argue that SSS is not a form of response habituation but just one instance of psychological satiation, more akin to boredom. Secondly, it is still unclear when meal variety is perceived as such. What exactly constitutes meal variety? Thirdly, I speculate that the presence of extra-oral taste receptors in the gastrointestinal tract function to extend SSS. Whether this is the case needs to be examined. The answers to these questions are especially important for effectively applying manipulations of food variety to be able to control food intake and food choice.

Samenvatting

Veertig jaar geleden (in 1981) werden twee artikelen gepubliceerd in het wetenschappelijke tijdschrift Physiology & Behavior, waarin een aantal experimenten werd beschreven naar ‘sensorisch-specifieke verzadiging’ en het ‘variatie-effect’, twee belangrijke determinanten van eetgedrag. Sensorisch-specifieke verzadiging houdt in dat wanneer je iets eet, dat eten steeds minder lekker wordt, terwijl eten dat je niet hebt gegeten even lekker blijft. Sensorisch-specifieke verzadiging beïnvloedt zo hoeveel je eet. Je stopt met eten zodra eten niet meer lekker is. In de hierboven genoemde experimenten uit 1981 merkten de onderzoekers naast sensorisch-specifieke verzadiging ook een ander, gerelateerd effect op. Wanneer ze hun proefpersonen een grotere variatie aan etenswaren voorschotelden, aten de proefpersonen meer dan wanneer er maar van één etenswaar gegeten kon worden. Dit zogenaamde ‘variatie-effect’ werd verondersteld samen te hangen met sensorisch-specifieke verzadiging. Als het eten van een specifiek gerecht niet meer lekker (genoeg) is, zal de mogelijkheid om iets anders (dat wel nog steeds lekker wordt gevonden) te eten ervoor zorgen dat je blijft eten.

Het standaardprotocol om het optreden van sensorisch-specifieke verzadiging te testen, is om proefpersonen te verzoeken een reeks etenswaren te proeven en beoordelen, waarna ze één van die etenswaren te eten krijgen (een vastgestelde hoeveelheid of zoveel als ze maar willen). Nadat ze klaar zijn met het eten van dat ene etenswaar proeven en beoordelen ze dezelfde reeks etenswaren opnieuw. Sensorisch-specifieke verzadiging is de verandering in hoe lekker het gegeten etenswaar wordt gevonden vergeleken met de verandering in hoe lekker de overige (niet gegeten) etenswaren worden gevonden. Het variatie-effect wordt getest door proefpersonen ofwel één etenswaar ofwel een reeks aan etenswaren voor te schotelen waarvan ze vrijelijk (ad libitum) mogen eten tot ze aangenaam vol zitten. Een andere manier om het variatie-effect te toetsen is door proefpersonen eerst een specifiek etenswaar te laten eten, waarna ze nogmaals hetzelfde eten of een ander etenswaar krijgen voorgeschoteld. Men kan spreken van een ‘variatie-effect’ als de proefpersonen meer eten wanneer ze een ander etenswaar krijgen voorgeschoteld. Zoals besproken in **Hoofdstuk 1** was het doel van dit proefschrift om beter te begrijpen hoe sensorisch-specifieke verzadiging en het variatie-effect zich tot elkaar verhouden, welke factoren van invloed kunnen zijn op sensorisch-specifieke verzadiging en het variatie-effect, en of ze een belangrijke rol spelen bij voedselkeuze.

In **Hoofdstuk 2** wordt een studie besproken waarbij de relatie tussen sensorisch-specifieke verzadiging en het variatie-effect werd onderzocht. We onderzochten het veronderstelde mechanisme tussen sensorisch-specifieke verzadiging en het variatie-effect. Proefpersonen in deze studie aten een ‘maaltijd’ die weinig gevarieerd of juist meer gevarieerd was. De weinig gevarieerde maaltijd bestond uit 5 ‘hapklare’ porties van etenswaar A en B (A-B-A-B-A-B-A-B-A-B) en de meer gevarieerde maaltijd bestond uit 5 ‘hapklare’ porties van etenswaar A en 1 ‘hapklare’ portie van etenswaar B, C, D, E, en F (A-B-A-C-A-D-A-E-A-F). De ‘maaltijden’ werden gegeten volgens een zogenaamde ‘signalled exposure procedure’ (kijken-ruiken-proeven-kauwen). Voor en na het eten van de maaltijd proefden en evalueerden de proefpersonen de zes etenswaren die in de maaltijden zaten en twee etenswaren die in geen van beide maaltijden werden gegeten. Deze evaluaties werden gebruikt om het optreden van sensorisch-specifieke verzadiging voor product A en B te testen. De mate van sensorisch-specifieke verzadiging voor product A was gelijk in beide maaltijden, maar voor product B trad er alleen sensorisch-specifieke verzadiging op wanneer er 5 hapklare porties werden gegeten (de weinig gevarieerde maaltijd). Deze resultaten wijzen erop dat voedselvariatie het optreden van sensorisch-specifieke verzadiging vermindert, doch enkel wanneer het de mate van zintuiglijke blootstelling aan het eten vermindert.

Vervolgens, in **Hoofdstuk 3**, onderzochten we of de eet-context belangrijk is voor sensorisch-specifieke verzadiging. Proefpersonen in dat onderzoek proefden en evalueerden een reeks van acht etenswaren, waarna ze van één van die etenswaren konden eten totdat ze aangenaam vol zaten. Daarna evalueerden ze opnieuw de reeks van acht etenswaren. Na die tweede evaluatie kregen ze ofwel hetzelfde etenswaar voorgeschoteld dat ze zojuist hadden gegeten, ofwel een ander etenswaar. Eén groep proefpersonen kreeg deze tweede ‘gang’ in dezelfde kamer en een andere groep kreeg deze tweede ‘gang’ in een andere kamer (een contextwisseling). De resultaten van dit onderzoek lieten zien dat de proefpersonen sensorisch-specifieke verzadiging ontwikkelden voor het etenswaar dat ze in de eerste ‘gang’ aten en dat ze meer aten van de tweede ‘gang’ als dit een ander etenswaar was (het variatie-effect). Het veranderen van de kamer waarin ze het eten voorgeschoteld kregen had geen effect op hoeveel ze aten, wat suggereert dat sensorisch-specifieke verzadiging niet kan worden geneutraliseerd door de omgeving waarin men eet te veranderen. Met andere woorden, sensorisch-specifieke verzadiging lijkt niet afhankelijk te zijn van de fysieke context waarin gegeten wordt.

Hoofdstuk 4 beschrijft een onderzoek waarbij de invloed van cognitieve ‘aanwijzingen’ op voedselinname en sensorisch-specifieke verzadiging werd onderzocht. We onderzochten daarbij of productlabels die informatie geven over hoe verzadigend een maaltijd is effect hebben op hoeveel wordt gegeten van zo’n maaltijd en de mate van sensorisch-specifieke verzadiging die optreedt voor de maaltijd. Proefpersonen in het onderzoek aten twee keer (op verschillende momenten) een pastasalade, waarbij de ene keer werd aangegeven dat de pastasalade een ‘vullende’ maaltijd was, terwijl de andere keer werd aangegeven dat het een ‘lichte’ maaltijd was. In werkelijkheid waren de pastasalades identiek. De proefpersonen konden zoveel eten als ze wilden van de maaltijd tot ze aangenaam vol zaten. Voor en na het eten van de pastasalade evalueerden de proefpersonen de pasta en nog zeven andere etenswaren om sensorisch-specifieke verzadiging te kunnen bepalen. We vonden dat de proefpersonen meer van de pastasalade aten wanneer die gelabeld was als ‘lichte’ maaltijd dan wanneer deze gelabeld was als ‘vullende’ maaltijd. Verrassend was dat de mate van sensorisch-specifieke verzadiging die ze ervoeren gelijk was in beide condities, ondanks het verschil in hoeveel er werd gegeten. Ook toen we de mate van sensorisch-specifieke verzadiging corrigeerden voor de hoeveelheid pasta die men had gegeten, zagen we geen verschillen tussen de condities. Met andere woorden, de consumptie van de pastasalade werd beïnvloed door de labels, maar er is geen eenduidig bewijs dat de labels ook invloed hadden op sensorisch-specifieke verzadiging.

Hoofdstuk 5 beschrijft twee studies die het relatieve belang van voedselvariatie voor voedselkeuze onderzochten. In twee online keuze-experimenten onderzochten we het relatieve belang van variatie, complexiteit en portiegrootte voor ijsvoorkeuren in een Nederlands en Amerikaans consumentenpanel. In Studie 1 vroegen we de respondenten om het ijs dat hun voorkeur had te kiezen uit een reeks opties die verschilden in hoe sensorisch gevarieerd en complex ze waren. In Studie 2 verschilden de ijsopties in mate van variatie en portiegrootte. Beide studies lieten zien dat variatie zeer belangrijk is voor ijsvoorkeuren. In Studie 1 had variatie de voorkeur boven complexiteit (maar ijs dat zowel gevarieerd als complex was, was het populairst). In Studie 2 was de smaak van het ijs belangrijker dan de portiegrootte en wanneer men moest kiezen tussen smaken had een variatie aan smaken de voorkeur. Deze resultaten werden zowel bij de Nederlandse als de Amerikaanse consumenten gevonden. Het enige verschil dat werd gevonden tussen de consumentenpanels in de twee landen was de voorkeur voor portiegrootte: de Amerikaanse consumenten prefereerden grotere porties dan de Nederlandse consumenten. Kortom, deze twee online keuze-experimenten suggereren dat vooral voedselvariatie een belangrijke factor is in voedselkeuze.

Recapitulerend bestendigt het onderzoek beschreven in dit proefschrift de onderstelling dat sensorisch-specifieke verzadiging een belangrijke (zoniet een sleutel-) rol speelt bij voedselinname en voedselkeuze, en dus van groot belang is voor het ontwikkelen van een gezond eetpatroon. Maar, zoals ik stel in **Hoofdstuk 6**, na vier decennia van onderzoek naar sensorisch-specifieke verzadiging blijven nog verschillende belangrijke vragen onbeantwoord. Ten eerste is het onduidelijk welk algemeen psychologisch mechanisme ten grondslag ligt aan sensorisch-specifieke verzadiging. Ik stel dat sensorisch-specifieke verzadiging geen vorm van responshabituatie is, maar een voorbeeld van psychologische verzadiging dat meer verwant is aan verveling. Ten tweede is het nog onduidelijk wanneer maaltijdvariatie ook wordt gezien als zodanig. Wat precies is het dat een maaltijd wel of niet gevarieerd maakt? Ten derde speculeer ik dat sensorisch-specifieke verzadiging wordt voortgezet door smaakreceptoren in het maagdarmkanaal. Of dat inderdaad het geval is, moet worden onderzocht. De antwoorden op bovengenoemde vragen zijn belangrijk voor het effectief toepassen van manipulaties van voedselvariatie om voedselinname en voedselkeuze te sturen.

Impact addendum

It is common knowledge that in the past decades the global prevalence of obesity has markedly increased (and is still rising). This is problematic as obesity is associated with dire health problems including depression, type 2 diabetes mellitus, cardiovascular disease, and various forms of cancer. The current COVID-19 pandemic also poses a significantly bigger health risk for obese individuals.

Weight gain is the result of a positive energy balance, when more energy is consumed than is expended. Unsurprisingly then, the increasing prevalence of obesity is linked to the increasing availability and consumption of high-energy, nutrient-poor foods. Population wide limits on energy intake would help prevent obesity and hence curb the obesity epidemic, but it requires a nutrition transition; that is, a shift from a diet rich in high energy dense/nutrient poor foods to a diet rich in mainly plant based nutrient dense foods. Attempts to alter dietary patterns and decrease obesity numbers have not been very successful. Clearly, there is still a need for effective strategies to encourage healthier dietary habits.

Overeating occurs in many situations. Within a meal context, serving large portions, eating while distracted, or a high eating rate can all promote overeating. Two important determinants of food intake – related to the sensory characteristics of food – were studied in this dissertation: sensory-specific satiation (SSS) and the variety effect (the variety of foods present in a meal). Increasing variety within a meal increases intake by delaying SSS (prolonging the pleasantness of the eating activity). This 'variety effect' has been shown across different food groups, eating occasions, cultures, and ages. Food variety and SSS are therefore undoubtedly important determinants of food consumption and – consequently – of weight-control, which can provide useful strategies to (1) increase or motivate intake of nutritious foods and (2) decrease intake or the desire to eat energy dense/nutrient poor foods, thus encouraging healthier dietary habits.

The aim of this dissertation was to expand our knowledge of these two important determinants of eating behaviour (SSS and the variety effect). A better understanding of SSS and the role of food variety in eating behaviour provides useful leads to establish a healthy dietary habit.

Impact on intake

The present thesis is a series of studies on SSS and an exercise in trying to identify relevant variables (food-related, contextual, or individual attributes) that, when manipulated, will affect SSS and hence eating behaviour. SSS and the variety effect are important determinants of what and how much we eat. More variety decreases the magnitude of SSS and increases food intake. Therefore, combining a variety of healthy foods in a meal will encourage intake of those foods (by prolonging eating pleasure). Implementing this principle across meals will result in increased consumption of nutritious food that will benefit health and wellbeing. Inclusion of more variety in meals could also be implemented as a 'nudge' to encourage meal intake in, for example, vulnerable patient populations or older adults.

Impact on food choice

Naturally, food intake determines energy and nutrient status (and thus affects weight status and health), but before food consumption commences, a choice is made regarding which foods to consume. Even when no choice in different food options is offered a choice still needs to be made whether or not to eat the food. Findings of this dissertation imply that SSS and the variety effect are not only important determinants for the amount of food consumed, but are also involved in food choice. In natural eating situations, what and how much is eaten is often determined by what (and how much) is purchased, which makes food choice a prominent determinant of healthy eating habits. Our findings suggest that including variety (and complexity) in healthy, nutritious products or meals might make these more attractive, and could thereby encourage individuals to choose and consume such meals or products. Conversely, including less variety in more nutrient-poor/energy-dense products could render these options less attractive.

Conclusion

In sum, this dissertation enhances our understanding of the effect of SSS and food variety on food intake, and extends these insights to food choice. Although these implications warrant further investigation, they can provide food designers and health promotors with novel strategies to encourage healthier food choices, and consequently, healthier dietary habits. Therefore, this dissertation provides a useful starting point for developing novel strategies, services, products, or interventions to foster better living through better eating.

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Curriculum Vitae

Anouk Elisabeth Matheus Hendriks-Hartensveld was born on August 31, 1993 in Sittard (the Netherlands). She graduated from secondary school in 2011 (Gymnasium, Trevianum scholengroep), after which she completed a bachelor of science in Health Sciences in 2014 with a major in Mental Health Care at Maastricht University (cum laude). She completed a master of science in Mental Health in 2015 (Maastricht University). During the master and bachelor, she completed two research internships in the research group Eating Disorders and Obesity at the department of Clinical Psychological Science (Maastricht University) studying the effects of cognitive training on eating behaviour. After obtaining her master's degree, she worked as a psychologist/social worker at an addiction clinic (Vincere ggz) and social service organization (LEVANTO groep). In March 2017, she started working as a research assistant at the department of Epidemiology (Faculty of Health, Medicine and Life Sciences) at Maastricht University, and started her PhD project in October 2017 at the Laboratory of Behavioural Gastronomy (Centre for Healthy Eating and Food Innovation) at Maastricht University Campus Venlo. During her PhD project, she studied sensory-specific satiation and the variety effect under supervision of Prof. Remco Havermans, Prof. Aalt Bast, and Prof. Chantal Nederkoorn. In 2019, she visited the Laboratory for the Study of Human Ingestive Behavior at The Pennsylvania State University (USA, PA), chaired by Prof. Barbara Rolls. Since October 2021, she is working as a postdoctoral researcher in the research group Eating Disorders and Obesity at the department of Clinical Psychological Science at Maastricht University.

A

Publications and presentations

Published manuscripts

Hendriks-Hartensveld, A. E. M., Brodock, J. L., Hayes, J. E., Rolls, B. J., Keller, K. L., & Havermans, R. C. (2022). The relative importance of complexity, variety, and portion size in ice cream preference in Dutch and American participants. *Food Quality and Preference,* 104523. https://doi.org/10.1016/j.foodqual.2021.104523

Hendriks-Hartensveld, A. E. M., Rolls, B. J., Cunningham, P. M., Nederkoorn, C., & Havermans, R. C. (2022). Does labelling a food as 'light' vs. 'filling' influence intake and sensory-specific satiation? *Appetite, 171,* 105916. https://doi.org/10.1016/j.appet.2022.105916

Hendriks, A. E. M., Nederkoorn, C., van Lier, I. M. J., van Belkom, B., Bast, A., & Havermans, R. C. (2021). Sensory-specific satiety, the variety effect and physical context: Does change of context during a meal enhance food intake? *Appetite, 163,* 105179. https://doi.org/10.1016/j.appet.2021.105179

Hendriks, A. E. M., & Havermans, R. C. (2020). 'Gatverdamme, je zou er maar zo uitzien'. Over gewichtsstigma versus gezondheid op elk gewicht. [About weight stigma versus health at every size]. *De Psycholoog, 55*(6), 10-17.

Havermans, R. C. & **Hendriks, A.** (2020). Over de waarde van expertise en de wijnkenner in het bijzonder. [On the value of wine expertise]. *De Psycholoog, 55,* 32-39. https://www.tijdschriftdepsycholoog.nl/wetenschap/over-de-waarde-van-expertise/

Hendriks, A. E. M., Havermans, R. C., Nederkoorn, C., & Bast, A. (2019). Exploring the mechanism of within-meal variety and sensory-specific satiation. *Food Quality and Preference, 78,* 103740. https://doi.org/10.1016/j.foodqual.2019.103740

Havermans, R. C. & **Hendriks, A. E. M.** (2019). Does MRI Acoustic Noise Affect Chemosensory Perception? *Chem. Percept., 13,* 11-18. https://doi.org/10.1007/s12078-019-09257-9

Havermans, R. & **Hendriks, A.** (2018). Waarom kinderen met kanker te weinig eten. [Why children with cancer don't eat enough]. *Nederlands Tijdschrift voor Voeding & Diëtetiek, 73*(4), 42-44.

Other manuscripts

Hendriks-Hartensveld, A. E. M., Nederkoorn, C., van den Brand, A., & Havermans, R. C. Vegetable neophobia is associated with risk avoidance for distaste in children. (in preparation)

van den Heuvel, E., & **Hendriks-Hartensveld, A. E. M.** Within-meal variety as strategy to promote food intake of older adults. (in preparation)

Presentations at international conferences

Hendriks-Hartensveld, A. E. M., Brodock, J. L., Hayes, J. E., Rolls, B. J., Keller, K. L., & Havermans, R. C. (2021). The relative importance of variety, complexity, and portion size in ice cream selection in Dutch and American participants. Poster presentation at the Pangborn symposium, online meeting.

Hendriks-Hartensveld, A. E. M., Rolls, B. J., Cunningham, P. M., & Havermans, R. C. (2021). Cognitive influences on sensory-specific satiation (SSS) and food intake. Poster presentation at the annual meeting of the British Feeding and Drinking Group, online meeting.

Hendriks, A. E. M., Havermans, R. C., Nederkoorn, C., & Bast, A. (2019). Exploring the mechanisms of within-meal variety and sensory-specific satiation. Oral presentation at the annual meeting of the British Feeding and Drinking Group, Swansea, United Kingdom.

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