Food characteristics and dietary intake

the role of taste, eating rate and energy density

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Abstract

The increases in obesity prevalence coincide with changes in our food environment, such as an increased consumption of processed, energy dense foods. This suggests that the foods we consume are at least partly responsible for the obesity epidemic. The aim of this thesis is therefore to investigate food characteristics, with the focus on **taste**, **eating rate** and **energy density**, and their relation to dietary intake.

Taste is studied in two respects. First, the contribution of taste qualities to the diet is investigated, using the Food Consumption Survey 2003. Foods are classified according to their predominant taste (sweet, salty or savoury, sour, bitter or neutral). Energy intake of the foods within taste categories is assessed, showing that the largest part (34%) of the daily energy intake originates from sweet foods. Second, it is investigated whether taste, which is supposed to be a nutrient sensor, can fulfil this function within the current diet. Intensities of the five basic tastes of 50 commonly consumed foods are therefore assessed and associated with the nutrient content. Positive associations are found between sweetness and mono- & disaccharides and between both saltiness and savouriness and sodium and protein. The associations are less pronounced in highly processed foods, which suggests that in these foods the ability to sense nutrient content based on taste is limited. The influences of an incongruence between sensory properties and nutrient content are also investigated, by examining the effects of fat perception on energy intake. We demonstrated that energy intake is almost 10% lower in case of visible fats compared to hidden fats, suggesting that hidden fats may contribute to overconsumption.

Eating rate seems to be associated with food intake. The contribution of eating rate to the diet is investigated, using the Food Consumption Survey 2003. Foods are classified into one of four eating rate categories, and energy intake of the foods within each category is assessed. Results demonstrate that foods with slow calories (kJ/min) provide 10%, whereas foods with fast calories provide 37% to the daily energy intake. So in the current diet, the consumption of foods with a high eating rate is high. The effects of eating rate on intake are also investigated, showing that eating rate is positively associated with food and energy intake. People may therefore be at risk of overconsumption, when consuming foods with a high eating rate.

Consuming **energy dense snacks** is often blamed for affecting energy balance, but findings are inconclusive. Therefore, effects of snack consumption on body weight are investigated. No changes in body weight are observed after 8 weeks, when energy density of snacks was either low or high. This suggests that consuming snacks does not necessarily contribute to weight gain, at least in normal-weight young adults.

In conclusion, when taste and other sensory properties do not accurately reflect the nutrient content, which applies particularly to highly processed foods, this may lead to high food intakes. In addition, a large part of the daily energy intake originates from foods with a high eating rate, which stimulates food and energy intake. So the high eating rate of the foods in the current diet may be responsible for overconsumption. These findings may be helpful in following the recommendations of the Nutrition Centre to lose weight. Last, even though we did not find evidence that consuming energy dense snacks results in weight gain, the advice should nevertheless be to limit the intake of energy dense foods, at least until evidence becomes more conclusive.

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General introduction

Obesity and the changing food environment

Currently, about half of the adult population in the Netherlands suffers from overweight or obesity: 41% of the male and 30% of the female adults are classified as overweight (BMI of 25.0 - 29.9 kg/m^2), whereas 11% of the male and 12% of the female adults are classified as obese (BMI > 30.0 kg/m^2)[1]. In addition, almost 12% of the children is overweight or obese; a prevalence that is expected to increase to 14% in 2020[2].

In parallel with the increased prevalence of obesity, our food environment has changed in the last few decades. Forty years ago, foods were mainly prepared at home and they were also eaten at home. Since then, technological innovations, such as vacuum packing, improved methods of preserving, and food processing have enabled the production and thus the consumption of ready-to-eat food products[3]. Food availability has increased as well. In our Western society there is an abundance of all kinds of different foods, ranging from meat and cheese to sugar sweetened beverages and sweet or savoury snacks[4]. The implication of these technological innovations and changes in food availability is that we now spend less time on preparing foods and that we consume less fruit and vegetables and more pre-prepared and ready-to-eat foods, especially during dinner[5]. In addition, our diet has become increasingly energy dense, with large increases in edible fats and oils and caloric sweeteners[6]. Another change in our food environment is that nowadays more energy is consumed in between meals than a few decades ago[7], although this finding is not consistently demonstrated[5]. Whether or not we now tend to consume more energy between meals, at least it appears that the foods we select as snacks has changed. This applies especially for beverages, which changed from coffee and tea to soft drinks[5].

As mentioned above, the observed changes in our food environment coincided with the increase in the prevalence of overweight and obese individuals, which suggests that our current way of eating and the foods we consume are at least partly responsible for the obesity epidemic. But what exactly is it in our current food pattern that makes us eat too much? The research described in this thesis was conducted to provide answers to this question, with the focus on food characteristics and their influences on our food intake. In this chapter, we first provide a framework of the main factors that influence food intake. Then, the food characteristics that were addressed in this thesis are introduced. Finally, the rationale and outline of the thesis are presented.

Factors that influence our food intake

The intake of food is a multifactorial behaviour, which is determined by three main factors: environmental factors, personal factors and food-related factors (**Figure 1.1**). These three factors exert a direct effect on food intake, but they also interact with each other to influence food intake.

Environmental factors can be divided into four types of environments[8]. The first is the physical environment, which refers to aspects like the availability of a variety of healthy and unhealthy foods and the access we have to these foods[9-11], but also to

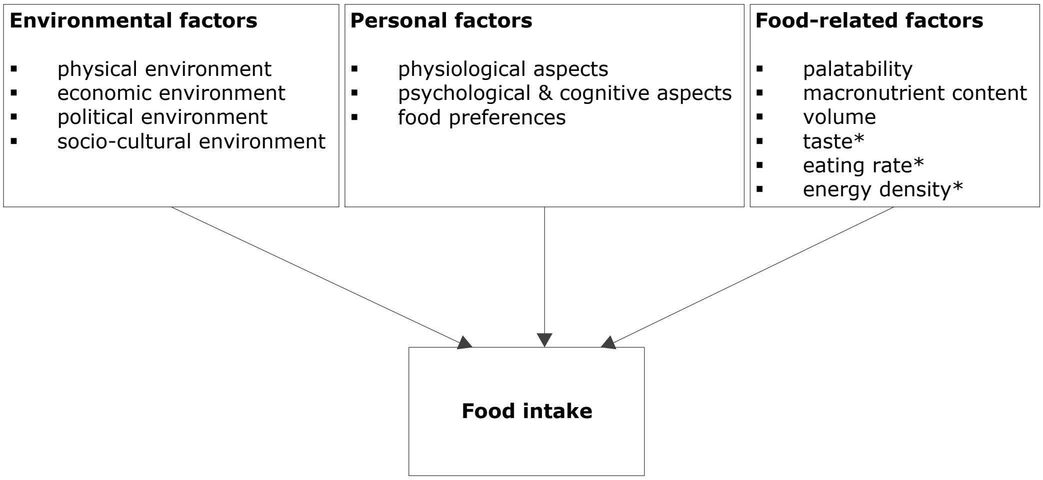

Figure 1.1 *The main factors that determine food intake. * indicates the factors that were studied in this thesis.*

aspects like the atmosphere in which we eat, such as the colour and amount of light we see, the music we hear and the odours we smell[12]. Another important aspect that can be considered as part of the physical environment, which has a large effect on our food intake is the portion size of a food. It has extensively been shown that larger portion sizes lead to a higher food intake[13-21]. The second type of environment is the economic environment, which refers to aspects such as food prices and household income[11, 22]. The third is the political environment, including nutrition policies but also rules and regulations that exist about foods and eating behaviour within families or schools[8]. The last one is the socio-cultural environment, which refers to cultural norms about foods and eating behaviour, but also to social influences of others, like support or pressure to engage in certain eating behaviours[10], or like the effects of the presence of other people on our food intake[23, 24].

Personal factors that influence food intake can be divided into physiological factors, psychological or cognitive factors, and food preferences[25]. From a physiological point of view, food intake starts with a feeling of hunger and the subsequent decision to eat. Food enters the mouth and the gastrointestinal tract, where it is masticated, digested and absorbed. Our brain receives signals from each part of the digestive tract, to inform us that food is entering our body and that nutrients will be absorbed[26-28]. These signals are integrated with hormonal signals from adipose tissue and when enough food has been ingested to meet our energy needs, we will feel satiated and terminate our food intake[27, 29]. After a while, the nutrients are either used or stored in our body and we again start to feel hungry; the process of ingesting, digesting and absorbing starts all over again. This process, which depends on age, gender and weight status[30-33], suggests that we are physiologically equipped to accurately regulate our food intake. However, as is clear from the current obesity epidemic, the regulatory system does not seem to work effectively in preventing a positive energy balance. This indicates that our physiological regulatory system can easily be overruled by other factors that influence food intake.

Psychological or cognitive factors that influence food intake include personality traits such as restrained eating (the tendency to restrict one's food intake)[34], impulsivity (the tendency to respond to cues, without thinking about possible consequences) and sensitivity to rewards[35]. Similarly, mood, paying attention to what we eat (monitoring our food intake) and the knowledge we have about (healthy) nutrition influence food intake as well[25, 34, 36].

An important aspect that drives food intake is the preference for a food. This can be considered both as a personal and as a food characteristic. Food preferences can either be innate, or can be learned through exposure to foods[37]. When a food is ingested, we associate sensory properties (like the taste, smell, and texture) of the food with the metabolic consequences of ingesting these foods[38, 39]. When these consequences are positive, like a pleasant feeling of satiety, the food that we ingested becomes pleasant: a preference for the food develops. When the consumption of a food results in unpleasant feelings, like digestive discomfort, we tend to avoid subsequent consumption[40, 41]. Clearly, it depends on our individual experiences with a food whether we like it or not. On the other hand, it also depends on the food itself whether or not we have a tendency to like this food: foods that contain much energy are likely to result in a satiated feeling and are therefore easily preferred. Food preferences can therefore also be considered as a food-related factor.

Food-related factors have a large impact on our food intake. This follows from studies that investigated the relations between dietary pattern and BMI status. It appears, for example, that women who consume an 'empty-calorie' diet, which is rich in calories, but poor in nutrients, are at increased risk of gaining weight compared to women who consume a 'heart-healthy' diet, which is nutritionally varied and low in fat[42]. Similarly, a dietary pattern high in wholegrain bread, fruits, raw vegetables and low in processed meat, butter and cheese seems protective against weight change[43], whereas the consumption of fast food meals is consistently demonstrated to be associated with weight gain[44-46]. Consuming sugar-sweetened beverages, like soft drinks, have also been shown to contribute to a high energy intake, which is uncompensated for[47, 48]. Clearly, some foods contribute to a positive energy balance, whereas other foods seem protective against an energy imbalance and thus against obesity.

One of the most potent food characteristics that influence our food intake is palatability. Clearly, we do not eat what we do not like, in a situation where we can choose what to eat. So the palatability of a food affects the choice we make on which foods to consume. In addition, palatability influences the amount we eat: the more we like a food, the more we eat of it[49]. When highly palatable foods are consumed, hunger is increased in the first part of a meal, an effect which is called the 'appetizer effect'[50, 51]. People also tend to eat faster and longer when they consume a palatable food, relative to a bland tasting food[52, 53]. So palatability influences our food intake through the choice we make and the amount we eat, by increasing both eating rate and meal duration.

Another important characteristic is the macronutrient composition of a food, which determines the food's energy content. Our energy intake therefore depends on the composition of the foods we ingest. There is considerable evidence that the different macronutrients exert different effects on satiety, where protein is the most satiating macronutrient, followed by carbohydrates, whereas fat is the least satiating macronutrient[54-56]. This suggests that a high fat intake easily results in a high energy intake, because of its relatively low satiating efficiency[32, 57, 58]. The fibre content of a diet seems protective against weight gain[59]. This suggests that a high fibre content helps to reduce food intake, most likely through the effects on satiety[60]. The macronutrient content of foods can also affect the palatability of a food, which applies especially for high fat and high sugar contents[61, 62].

Furthermore, volume of food is a characteristic that influences the amount of food we consume: increasing the volume, while keeping energy content stable, results in a lower intake[63-65]. One of the underlying mechanism is that stomach distension, which occurs when a certain volume of food enters the stomach, triggers feelings of fullness and satiety, which eventually results in meal termination[66]. It is even suggested that volume of a food has a greater influence on satiety than the food's energy content[67], although this is not consistently demonstrated[68].

Other food characteristics that affect our food intake are taste, eating rate, and energy density. These characteristics were studied in this thesis and will therefore be introduced in detail in the following paragraph.

Food characteristics studied in this thesis

Taste

The taste system is a guardian of the human body, which initially predicts how an item would affect the body: does it provide nutrition or will it cause illness[69]. Next, when an item is identified as a food, its taste is expected to represent some of the foods' components[70]. Bitter tastes, for example, may signal toxic compounds, whereas sourness may signal a low pH or unripe foods[70, 71]. Similarly, it is assumed that a sweet taste signals the carbohydrate and energy content, whereas a savoury taste signals the protein content[72]. This latter suggests that taste is a nutrient sensor: the taste of a food is predictive of the nutrients that are present in a food and is thus predictive of the nutrients that are about to enter our body. Considering its function as nutrient sensor, it is not surprising that the taste of a food is a driving force behind our food selection and intake[40, 41, 54, 73-75].

It seems that the taste of our diet is subject to change. For example, the diet of our ancestors most likely did not contain much sweet tasting foods; the only sweet foods were fruits and honey, both of which were only available during some months a year[76]. Nowadays, many of the foods we consume appear to be sweet[77]. These changes in the taste of our diet, and especially the increased consumption of sweet tasting foods, may underlie the high prevalence of obesity we face nowadays: we have an innate preference for the sweet taste. It may therefore be hard to resist the consumption of sweet foods, when they are available. So when we are exposed to many sweet tasting foods, we may consume (too) much of these foods. Little is known, however, on the relative contribution of each taste to our current food pattern. To the best of our knowledge, there is only one study that investigated this, showing that 47% of the total energy intake originates from sweet foods and 39% from salty foods, whereas only 9% and 5% of the total energy intake originated from sour and bitter foods, respectively[78]. These data were, however, based on 35 subjects and originated from 1985, so they can hardly be considered as representative of our current diet. In order to investigate whether taste, and changes in the taste of our diet over time, are indeed associated with obesity, more insight into the relative contribution of taste within the diet is necessary.

Currently, the food industry develops many foods that most of all need to be palatable and attractive to eat. In the production process compounds, such as aromas and flavour enhancers are added to increase palatability. Less attention is paid to whether taste and other sensory properties of these foods are still in line with the nutrient content. It may be that in our current food supply, where many foods are highly processed[79], taste is to some extent disconnected from its nutritional properties. A clear example is the use of non-caloric sweeteners, that provide a sweet taste, but do not provide any energy. Similarly, high-fat foods, like pastries, are not always identified as being high in fat[80, 81], because they lack the sensory properties that are associated with fat, like creaminess and crispiness[82]. A consequence of a disconnection between taste and nutrient content is that taste may lose its function as nutrient sensor. So far, there are no data available that provide information about whether the taste of the foods we consume nowadays is in accordance with the nutrient content. Moreover, it is not fully clear how a discrepancy between taste and nutrient content would affect our food intake. Research focusing on fat replacers, where sensory properties of fat were maintained, without the appropriate energy, demonstrated that energy intake decreased[74, 75, 83, 84]. This indicates that food intake was based primarily on the sensory properties of the food. This is beneficial in case foods provide less energy than could be expected based on its sensory properties. However, the problem in our current diet is that many foods likely contain more energy than could be expected based on their sensory properties. The contribution of (in)appropriate sensory signals to our food intake therefore needs to be investigated further.

Eating rate

As compared to the diet of our ancestors, we now consume increasingly more energy that can be ingested quickly, for instance in the form of energy yielding beverages and highly processed fast foods[85-87]. So the eating rate of our diet, i.e. the speed in which foods are ingested, seems to have increased. Recently, eating rate has gained attention as a determinant of our food intake, where eating rate has been shown to positively affect food and energy intake[88]. Cross-sectional[89-91] and experimental[92-94] studies also showed that eating rate was positively associated with BMI, which may suggest that individuals who consume foods at a fast rate are prone to develop overweight. A proposed mechanism is that because of a high eating rate, the oral exposure to the food is limited. Due to this limited oral exposure, few signals from the oral cavity may reach the brain[26], resulting in a limited satiety response. In turn, this limited satiety response would then result in a high food intake[95-98].

The available literature on eating rate mainly considered eating rate as a personality trait: there are individuals that in general eat slowly and there are individuals that in general eat quickly. However, eating rate can also be considered as a food characteristic, where some foods, such as water or soft drinks, can be ingested very fast, whereas other foods, such as steak or bread, require considerable mastication before a bite can be swallowed. So far, eating rate has not yet been studied as food characteristic. Besides based on common sense, little is known about the actual variation in eating rate between foods. This is nevertheless very relevant, because differences between foods may be large. In view of the positive relation between eating rate and intake, and the presumably large differences between foods, it may matter which foods we select in terms of eating rate, in order to maintain energy balance. This requires further investigation. In addition, because BMI has been positively associated with eating rate[89-91], where eating rate was not clearly defined as personality trait or food characteristic, the observed associations could be the result of differences in food choice, rather than the individual's trait to eat fast. In other words, people with a high BMI could select those foods which can be ingested relatively quickly, which in turn may lead to a high intake, compared to people with a normal BMI. This needs further studying, for this would provide useful tools in the struggle against obesity.

Energy density

As mentioned before, our diet has become increasingly energy dense, with large increases in the consumption of fat and sugar[6]. Energy density is determined by the macronutrients and water content of a food, with fat and water exerting the largest influence on energy density[99]. Because we tend to base our food intake on the volume or weight of foods, the energy density of foods has a large impact on our energy intake[100]. Several short term experiments indeed showed that there is no adequate compensation for increases in the energy density of foods[15, 101, 102]. Moreover, some long term intervention studies demonstrated that a low total dietary energy density facilitates weight loss[103, 104], whereas observational studies demonstrated that a high total dietary energy density contributes to weight gain[105, 106]. This indicates that dietary energy density clearly affects our energy intake[66].

Energy density differs between types of food. Foods that are habitually consumed as snacks are generally high in energy density, compared to foods that are habitually consumed at a meal[107]. This suggests that because of their high energy density, eating snacks is an important contributor to the obesity epidemic. Some short term, laboratory-based intervention studies indeed demonstrated that total daily energy intake increased, when energy dense snacks were consumed[108, 109], providing support for the suggestion that consuming energy dense snacks contributes to weight gain. However, observational studies do not provide consistent evidence on the associations between snack consumption and body weight status[110-114]. These inconsistent findings prevent us from making clear recommendations on snack consumption for body weight control. The effects of consuming energy dense snacks on energy balance therefore warrant further investigation.

Rationale & outline of the thesis

As is clear from the above discussed literature, our food intake is, besides environmental and personal factors, mainly determined by food-related factors. Factors like palatability and macronutrient content have already been studied extensively. However, the impact of taste, eating rate and energy density are not fully elucidated:

Changes in the basic taste qualities (sweetness, saltiness, savouriness, bitterness and sourness) of our diet may underlie the high prevalence of obesity. Little is known, however, on the contribution of the taste qualities to our current diet, based on food consumption data. But in order to study the association between taste and obesity, insight into the contributions of the taste qualities to the diet is required.

An important change in the current diet, is the consumption of foods that can be ingested quickly. There are indications that eating rate is associated with food intake and obesity. So far, however, eating rate as food characteristic has been unexplored. Insight is therefore needed into differences in eating rate between foods and into the associations with food intake. Moreover, insight into the contribution of eating rate to our food intake is required in order to study eating rate of foods as a possible factor in the aetiology of obesity.

In view of the large contribution (ca. 60%) of highly processed foods to our food intake, where taste may be disconnected from the nutrient content, it is not clear whether taste can still serve as a nutrient sensor. Nor is it clear how a discrepancy between taste and other sensory properties and the actual nutrient content would affect our food intake. This requires further studying.

The consumption of energy dense snacks is often blamed for being a causal factor for obesity. But because evidence is inconsistent, more research is needed to answer the question whether consuming energy dense snacks indeed may facilitate a positive energy balance and thus weight gain.

Insight into the above mentioned issues provides us with useful tools in the struggle against obesity. These insights are useful for making public health recommendations on weight management, for health professionals in advising patients in their attempts to reduce their energy intake, and for the food industry in order to develop palatable foods that provide a satisfactory level of satiety, without providing too much energy. Research described in this thesis was therefore conducted to provide these insights. The overall aim was *to study the food characteristics taste, eating rate, and energy density in relation to dietary intake.* The specific research questions that we addressed in this thesis are:

What is the contribution of the taste qualities and eating rate to our current diet?
In **chapter 2** we investigated the food intake of young adults in terms of taste and eating rate, using data from the Dutch Food Consumption Survey of 2003. Foods were first classified according to their predominant taste (either sweet, salty or savoury,

sour, bitter or neutral) or according to their eating rate (ranging from a slow to a fast eating rate, in g/min or kJ/min). Then, food and energy intake from each taste and eating rate category were assessed.

Can taste serve as a signal for the nutrient content of foods within our current diet?
In **chapter 3** we investigated the associations between the five basic taste qualities (sweetness, saltiness, savouriness, sourness and bitterness) and the nutrient content of commonly consumed foods. We separated the highly processed foods from the moderately processed and unprocessed foods, to investigate whether the associations between taste and nutrient contents depends on the level of processing of the foods.

To what extent is our food intake and energy balance influenced by the sensory perception of fat, eating rate of foods, and energy density of snacks?
Chapter 4 describes two studies where we investigated the influences of sensory perception of fat on food intake. The fat content of foods in a lunch was either clearly perceived by subjects, or foods were manipulated in such a way that foods did not appear to be fat, while in both cases macronutrient composition was equal. Food and energy intake during lunch or during following meals was measured. In **chapter 5** we measured the eating rate of commonly consumed foods and we measured the ad libitum food intake from each of the foods. We investigated the associations of eating rate with the food intake and the macronutrient composition, to explore which macronutrients were related to eating rate. **Chapter 6** describes an experiment where subjects consumed snacks either low or high in energy density, either between meals or during meals, for a period of 8 weeks, to investigate whether energy density of snacks affects longer term energy balance. Body weight and body composition were measured to reflect this longer term energy balance.

In the final chapter (**Chapter 7**), the results of the studies presented in this thesis are summarized and discussed and the implications and directions for future research are provided.

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2

Contributions of taste and eating rate to daily energy intake

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Abstract

Our food supply is subject to change, with possible augmentations in sweet foods and in foods that can be eaten quickly. These changes may be related to obesity. The objective of this study was to describe the current diet according to taste and eating rate of foods. Food consumption data of 358 young adults (aged 25.1 (SD 3.6) y, BMI of 22.5 (SD 2.7) kg/m^2) were obtained from the Dutch National Food Consumption Survey, 2003. Foods were classified into one of four eating rate categories in g/min (from low to high eating rates) and kJ/min (from slow to fast calories) and into one of 5 taste categories (sweet, salty/savoury, sour, bitter or neutral). Mean energy intake per category was assessed. Foods with low eating rates provided 47%, whereas foods with high rates provided 18% of energy intake. Foods with slow calories provided only 10% of daily energy intake, whereas foods with fast calories contributed 37% to daily energy intake. Most of daily energy intake originated from sweet (34%), neutral (30%) and salty/savoury (25%) foods. Bitter and sour foods provided only 6% and 4% of energy intake, respectively. Results showed that a large part of the energy intake originated from foods with high eating rates and fast calories and sweet foods. It is in these aspects that the current diet seems to have changed, which may underlie health problems, like obesity. Reversing trends in consuming more sweet or fast foods may help to prevent increases in obesity prevalence.

Introduction

Since the introduction of agriculture and animal husbandry, the characteristics of our food supply have started to change, with the largest changes having occurred since the Industrial Revolution, 200 years ago[1]. One of these changes is an increased consumption of energy that can be ingested quickly. First, our diet consisted of foods high in protein and fibre, which required sufficient chewing[2], and we drank mainly water. This implies that we did not ingest any energy at a fast consumption rate. Now, we do ingest energy at a fast consumption rate, in the form of energy yielding beverages and highly processed fast foods, that require little oral processing and can thus be ingested quickly[3-5].

Another change in our food supply, as suggested by Popkin and Nielsen (2003), is that our diet is becoming increasingly sweet[6]. Whereas in the early days of our existence, the only sweet foods were fruit and honey, which were only available a few months a year, now many of the foods we consume are sweet, like candy, pastries, desserts and many beverages. Currently, the intake of refined sugars is even estimated at 20% of our total energy intake[1].

The changes in our food supply may be partly responsible for the obesity problems we face nowadays. For instance, eating rate, the speed in which a food can be ingested, has been shown to positively affect food and energy intake[7-9]. Together with an increased consumption of foods with a high eating rate, this may imply that the increased eating rate of our food is a causal factor for obesity. In order to investigate the associations of eating rate and taste with obesity, insight is needed in the actual contributions of eating rate and taste to our current diet. So far, however, no attempts have been made to investigate our food intake in terms of eating rate. Considering taste, there has only been one study that investigated energy intake according to taste. Mattes (1985) showed that 47% of the total energy intake originated from sweet foods and 39% from salty foods, whereas only 9% and 5% of the total energy intake originated from sour and bitter foods, respectively[10]. These data were, however, based on 35 subjects and originated from 1985, so they are not representative of our current diet.

The currently available data on eating rate and taste leaves us at this moment with an incomplete picture of the contributions of these food characteristics to our current diet. In the present study, we therefore described our food intake according to taste and eating rate of foods. This provides new insights into our food pattern, which can be used to investigate differences between groups of individuals or for future comparisons with the current food consumption data, to investigate changes in our diet over time.

Methods

National Food Consumption Survey

Food consumption data were used from The National Food Consumption Survey, 2003, which assessed food intake using 2x24h dietary recalls of 750 young adults, aged 19-

Table 2.1 Characteristics of the food items per eating rate category in **g/min** as consumed in the Dutch National Food Consumption Survey[11].

	Category 1 (< 50 g/min)	Category 2 (50 – 100 g/min)	Category 3 (100 – 350 g/min)	Category 4 (> 350 g/min)
Food items, *n*	365	372	83	105
Energy density[1]	1271 ± 695	904 ± 836	463 ± 419	303 ± 382
Protein[1]	10.0 ± 8.3	5.7 ± 6.9	3.3 ± 4.3	1.0 ± 2.2
Fat[1]	14.2 ± 13.8	15.6 ± 23.8	3.8 ± 7.3	1.2 ± 4.5
Carbohydrate[1]	33.6 ± 29.1	12.0 ± 18.2	13.4 ± 12.7	13.7 ± 19.5
Fiber[1]	2.4 ± 3.2	1.2 ± 2.4	0.5 ± 1.5	0.2 ± 0.6
Alcohol[1]	0.0 ± 0.4	0.8 ± 4.7	1.3 ± 3.6	0.3 ± 1.7
Water[1]	37.3 ± 31.3	63.3 ± 25.8	76.1 ± 20.8	79.2 ± 26.6

[1]Data presented as mean ± SD; Energy density is presented as kJ/100g; macronutrients, fibre, and alcohol are presented as g/100g

30 years[11]. A detailed description of the data collection is published elsewhere[12]. In short, the dietary intake of subjects was assessed through a telephone interview on two non-consecutive days, by trained dieticians. Food intake, i.e. food type and amount consumed, was reported per eating occasion. In addition, subjects provided information on their body weight (kg) and height (m), from which BMI (kg/m^2) was calculated. Because underreporting is present in these data, we excluded subjects who underreported their food intake, determined as energy intake (EI) / basal metabolic rate (BMR) < 1.35[13]. BMR was based on the gender and body weight[14]. The final sample consisted of 202 men and 156 women, aged 25.1 (SD 3.6) y, with a mean BMI of 22.5 (SD 2.7) kg/m^2 and an EI/BMR ratio of 1.7 (SD 0.3).

Dutch Food Composition Table

The National Food Consumption Survey uses the Dutch Food Composition table 2001[15] to assess energy and nutrient intake. For the current study, we assigned each of the food items in this table to different categories for either eating rate or taste. We defined eating rate as grams per minute (g/min) or as kilojoules per minute (kJ/min); the foods were assigned to one of four eating rate categories. Similarly, foods were assigned to one of 5 taste categories (sweet, salty/savoury, sour, bitter & neutral), depending on their predominant taste. So we created three new variables to the Food Composition table. The Appendix shows the rules that we applied to classify the foods into eating rate or taste categories. The actual Food Composition Table including the new variables are available on request.

Eating rate in g/min

We based the classification of eating rate in g/min on a previous study, where we measured the eating rate of 45 food items, which ranged from ca. 5 – 650 g/min[9]. We made 4 categories, with eating rates < 50 g/min (category 1, mainly solid foods), between 50 – 100 g/min (category 2, mainly solid foods), between 100 – 350 g/min (category 3, mainly semi-solid foods), and > 350 g/min (category 4, mainly liquids). We compared the food items from the Food Composition Table with the foods that we used in our previous study. For example, we measured the eating rate of apple mousse and we assumed that other fruit mousses have comparable eating rates as apple mousse. We also took into account temperature, texture, viscosity, and alcohol percentage (see Appendix). In addition to the food characteristics, we also took into account that foods are often consumed in combination with other foods. Salad dressing, for instance, is usually consumed on top of salad; the eating rate of the dressing is therefore similar to that of salad and is also classified into the same eating rate category as salad. In case when yoghurt and milk were consumed with breakfast cereals, we adapted their eating rate category, because the eating rate of yoghurt or milk together with cereals differs largely from the eating rate of these foods separately. **Table 2.1** provides an overview of the macronutrient composition of the foods within eating rate categories (g/min).

Table 2.2 Characteristics of the food items per eating rate category in **kJ/min** as consumed in the Dutch National Food Consumption Survey[11].

	Quartile 1	**Quartile 2**	**Quartile 3**	**Quartile 4**
Food items, *n*	232	231	231	231
Energy density[1]	256 ± 237	1006 ± 516	1275 ± 783	1230 ± 924
Protein[1]	6.2 ± 8.4	8.7 ± 8.0	7.1 ± 6.8	4.6 ± 6.4
Fat[1]	1.8 ± 3.1	8.9 ± 9.9	16.7 ± 14.8	22.2 ± 28.0
Carbohydrate[1]	4.9 ± 6.9	31.1 ± 27.9	29.2 ± 26.0	18.2 ± 24.2
Fiber[1]	1.5 ± 1.9	1.7 ± 2.5	1.7 ± 2.5	0.9 ± 3.5
Alcohol[1]	0.0 ± 0.0	0.0 ± 0.5	1.2 ± 5.4	0.7 ± 3.5
Water[1]	82.0 ± 17.4	47.3 ± 27.8	42.1 ± 34.9	52.4 ± 29.5
Food groups[2], *n*	Potatoes, 5 (non) Alcoholic drinks, 16 Bread, 1 Eggs, 2 Fruit, 19 Cereals, 1 Vegetables, 83 Cheese, 1 Herbs & spices, 6 Dairy, 6 Legumes, 6 Soup, 18 Sweets, 1 Fats & oils, 11 Fish, 7 Meat & poultry, 41 Other, 8	Potatoes, 10 (non) Alcoholic drinks, 2 Bread, 34 Eggs, 2 Fruit, 8 Pastries, 49 Cereals, 3 Vegetables, 3 Cheese, 22 Herbs & spices, 3 Dairy, 21 Nuts & snacks, 2 Legumes, 1 Soup, 1 Soy products, 4 Sweets, 22 Fats & oils, 17 Fish, 3 Meat & poultry, 20 Other, 4	(non) Alcoholic drinks, 27 Bread, 4 Fruit, 4 Pastries, 41 Cereals, 9 Vegetables, 1 Cheese, 4 Herbs & spices, 1 Dairy, 25 Nuts & snacks, 30 Soy products, 4 Sweets, 33 Fats & oils, 16 Fish, 8 Meat & poultry, 15 Other, 9	(non) Alcoholic drinks, 49 Pastries, 1 Cereals, 19 Cheese, 6 Dairy, 48 Nuts & snacks, 4 Soy products, 2 Sweets, 8 Fats & oils, 57 Fish, 1 Meat & poultry, 24 Other, 12

[1]Data presented as mean ± SD; Energy density is presented as kJ/100g; macronutrients, fibre, alcohol and water are presented as g/100g

[2]Food groups, including the number of food items, that are present within eating rate categories[15]

Eating rate in kJ/min

Eating rate in **kJ/min** is determined by eating rate in g/min multiplied by the energy density (ED) of a food item. Our starting point to estimate the food's kJ/min was its eating rate category in g/min as described above. We assumed that foods within the first eating rate category (<50 g/min) would have a mean eating rate of 25 g/min. Similarly, we assumed a mean eating rate of 75 g/min for the second eating rate category (50 – 100 g/min); 225 g/min for the third category (100 – 350 g/min); and 500 g/min for the fourth category (> 350 g/min). To obtain an estimate of kJ/min, we then multiplied the mean eating rate in g/min with the ED of the individual food items. As mentioned above, we previously measured eating rate of 45 food items. So for these 45 food items, we actually know the eating rate in kJ/min. To estimate the accuracy of the calculated kJ/min that we propose here, we correlated the calculated kJ/min with the measured kJ/min of the 45 foods, which had an r = 0.90, $P < 0.01$. Next, in order to make four categories, we divided the food items into quartiles, based on the calculated kJ/min, where food items with the lowest eating rate in kJ/min were in the first quartile. **Table 2.2** provides an overview of the macronutrient composition of the foods within eating rate categories (kJ/min), and the food groups present in each category.

Taste

Food items were also classified according to their predominant taste: sweet, salty or savoury, sour, bitter or neutral. Saltiness and savouriness are two separate basic tastes. In a recent study, however, we demonstrated that the salty taste intensity of foods is highly correlated with their savoury taste intensity (r = 0.92), which implies that it may not be able to make a clear distinction between these two tastes (chapter 3). We therefore made one category for these two tastes. In this same study, we measured taste intensity of 50 food items, which provided us with a predominant taste of these items. Based on these data, we classified all food items from the Food Composition Table into a taste category. Foods which had a taste intensity for all basic tastes of <3 on a 15-point scale were classified as being neutral. See Appendix for a detailed overview of how we classified foods into taste categories. **Table 2.3** gives an overview of the macronutrient composition of the foods within the taste categories.

Table 2.3 Characteristics of the food items per taste category as consumed in the Dutch National Food Consumption Survey[11].

	Sweet	**Salty & savoury**	**Sour**	**Bitter**	**Neutral**
Food items, *n*	369	292	51	50	163
Energy density[1]	974 ± 742	1032 ± 647	378 ± 526	251 ± 337	1092 ±1042
Protein[1]	3.6 ± 3.7	13.3 ± 9.1	1.9 ± 2.4	2.0 ± 3.5	4.5 ± 4.7
Fat[1]	8.5 ± 11.4	17.5 ± 16.4	5.1 ± 13.9	1.0 ± 3.8	17.7 ± 30.2
Carbohydrates[1]	33.8 ± 27.0	9.3 ± 16.6	8.8 ± 13.2	3.7 ± 5.8	21.3 ± 25.0
Fiber[1]	1.4 ± 1.9	0.9 ± 1.9	0.8 ± 1.0	2.2 ± 4.8	2.8 ± 4.0
Alcohol[1]	0.6 ± 3.6	0.0 ± 0.2	0.3 ± 1.5	4.0 ± 9.4	0.0 ± 0.0
Water[1]	48.9 ± 35.7	57.0 ± 23.9	82.4 ± 17.3	85.0 ± 19.4	52.7 ± 33.7

[1]Data presented as mean ± SD; Energy density is presented as kJ/100g; macronutrients, fibre, and alcohol are presented as g/100g

Data analyses

The Food Composition Table, including the three new variables we created, was connected to the Food Consumption Survey. Mean dietary intakes over the two 24h dietary recalls were then calculated per eating rate and taste category. Analysis of variance was performed using SAS version 9.1.2 (SAS Institute Inc. 2004, USA), with PROC MIXED to investigate energy intake (kJ) and food intake (g) between eating rate or taste categories. The eating rate or taste category was treated as fixed factor. Subject was treated as a random factor. Adjustments were made for total energy or food intake by adding these variables to the model as covariates. Age and gender were considered as covariates as well, but they were not significant in any of the analyses. Tukey's tests were used for post hoc analyses. Presented P values represent differences of the taste or eating category with all other categories; P values < 0.05 were considered significant.

Results

Mean total food intake was 3.6 (SD 1.0) kg. Food intake differed between men and women, with 3.9 ± 1.0 kg for men and 3.1 ± 0.8 kg for women ($P < 0.01$). Total energy intake was 12.1 (SD 2.8) MJ. Total energy intake differed between men and women, with 13.6 (SD 2.6) MJ for men and 10.0 (SD 1.6) MJ for women ($P < 0.01$).

Eating rate in g/min: fast foods

The food intake (kg) from categories 1 and 2, containing mainly solid foods that can be ingested slowly, was similar, with 0.57 (SD 0.19) kg from category 1 and 0.49 (SD 0.21) kg from category 2. However, energy intake (kJ) did differ significantly ($P < 0.01$), where most of the daily energy intake originated from category 1, with 47% of daily energy intake, whereas 28% originated from category 2 (**Figure 2.1**). Foods from category 1 were the largest source of daily carbohydrate intake (53%), daily fibre intake (70%), and daily protein intake (54%) (all $P < 0.01$). Foods from category 2 were the largest source of daily fat intake (49%, $P < 0.01$). By far most of the daily food intake (1.6 (SD 0.9) kg or 45%) originated from food items within the fourth eating rate category ($P < 0.01$), so from foods that can be ingested very fast, mainly beverages. Despite of the highest food intake, energy intake from this category was 18% of total energy intake. Foods from the fourth category were the largest source (50%) of the daily water intake ($P < 0.01$).

Eating rate in kJ/min: fast calories

Most of the daily food intake (1.5 (SD 0.7) kg or 43%) originated from foods from category 1 ($P < 0.01$), so the foods with the 'slow calories'. Despite of the highest food intake from category 1, energy intake from this category was lowest, providing only 10% to daily energy intake ($P < 0.01$) (**Figure 2.2**). Foods from the first category were the largest source of the daily water intake (48%), and the smallest source of daily carbohydrate (10%) and fat (7%) intake (all $P < 0.01$). The second largest contributor of the daily food intake (1.2 (SD 0.9) kg or 35%) were foods from category 4, the foods with the 'fast calories'. The largest part of the daily energy intake (37%)

originated from foods within the fourth category. Foods from the fourth category were the largest source of the daily fat intake (49%, *P* < 0.01) and the smallest source of daily fibre intake (7%, *P* < 0.01). Food intake from categories 2 and 3 were lowest (0.4 (SD 0.2) kg and 0.4 (SD 0.3) kg, respectively), but provided 31% and 21% of the daily energy intake. Foods from category 2 were the largest source of daily carbohydrate intake (40%), daily protein intake (34%), and daily fibre intake (44%) (all *P* < 0.01). Foods from category 3 were the smallest source of daily protein intake (19%, *P* < 0.01).

Taste

Most of the foods (n = 369) that are consumed in the Netherlands are predominantly sweet (Table 3), followed by foods that are predominantly salty or savoury (n = 292) and neutral foods (n = 163). There were only a few foods that were either predominantly sour (n = 51) or bitter (n = 50). Food intake was highest from both sweet (1.1 (SD 0.5) kg or 31%) and bitter foods (1.1 (SD 0.8) kg or 31%). The energy intake from sweet foods was also the highest from all taste categories, with 34% of daily energy intake (*P* < 0.01) (**Figure 2.3**). Sweet foods were the largest source of daily carbohydrate intake (48%, *P* < 0.01). The high contribution of bitter foods came from items such as coffee, tea and some alcoholic beverages. The food intake from bitter foods therefore consisted of 98% of water. So despite of the high food intake, the energy intake from bitter foods was only 6% of the daily energy intake. Bitter foods were the largest source of daily water intake (37%, *P* < 0.01), but the smallest source of daily fat (0.3%, not different from sour foods, but compared with other tastes *P* < 0.01), carbohydrate (3.6%, *P* < 0.01), and protein (3.0%, not different

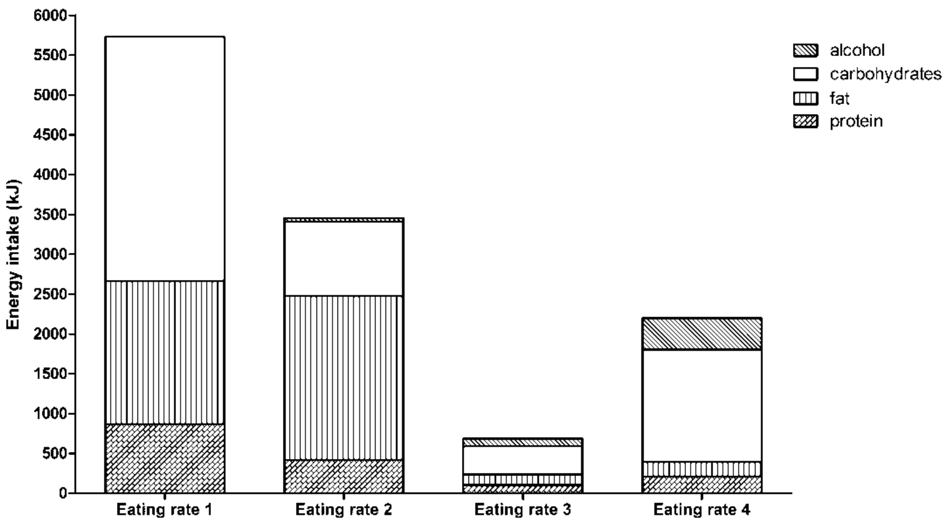

Figure 2.1 *Mean + SE energy intake of 358 young adults, per eating rate category in* ***g/min****, ranging from a low eating rate, ('slow foods' in category 1) to a high eating rate ('fast foods' in category 4). Energy intake differed significantly between all categories (P<0.01).*

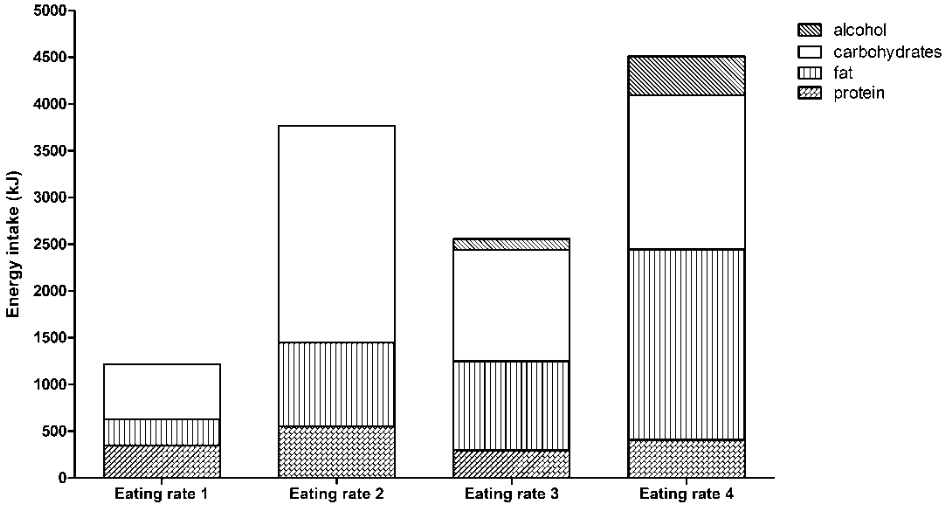

Figure 2.2 *Mean + SE energy intake of 358 young adults, per eating rate category in* ***kJ/min****, ranging from a low eating rate ('slow calories' in category 1) to a high eating rate ('fast calories' in category 4). Energy intake differed significantly between all categories (P<0.01).*

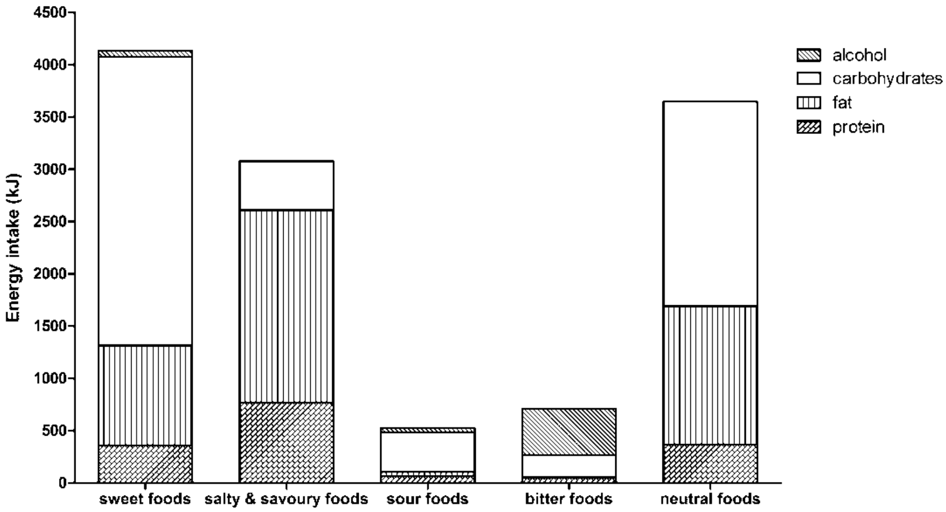

Figure 2.3 *Mean + SE energy intake of 358 young adults, per taste category. Energy intake from sour and bitter foods was equally high (n.s.); all other comparisons were significantly different (P<0.01).*

from sour foods, but compared with other tastes $P < 0.01$) intake. The next largest contributor to the daily food intake were the neutral foods, which provided 0.8 (SD 0.5) kg or 21% ($P < 0.01$) to daily food intake. The energy intake from neutral foods was 30% of daily energy intake. Neutral foods were by far the largest source of daily fibre intake (57%, $P < 0.01$). Food intake of salty or savoury foods was only 0.3 (SD 0.1) kg or 10% of the daily food intake, but provided 25% of the daily energy intake. Salty or savoury foods were the largest sources of the daily fat intake (44%) and daily protein intake (48%) (both $P < 0.01$). Sour foods provided, together with salty or savoury foods, the lowest proportion (0.3 (SD 0.3) kg or 7%) to total food intake (for other tastes $P < 0.01$). Similarly, sour foods provided, together with bitter foods, the lowest proportion (4%) to total energy intake (for other tastes $P < 0.01$).

Discussion

In this study, we investigated our food intake in terms of eating rate and taste, to gain insight into the contributions of these food characteristics to our current diet. The main finding regarding eating rate in g/min is that most of the food intake originated from foods that can be ingested quickly, which were mainly beverages. And because of this high food intake, the actual energy intake was also rather high, with 18% of the total daily energy intake. In itself, 18% may not be such a huge proportion, but when we consider that we used to consume hardly any energy at such high eating rates (>350 g/min)[1], this shift towards the intake of "fast energy" appears a major change in our diet.

Because in general beverages do not elicit a large satiety response[16], we can assume that the consumption of foods within the fourth eating rate category (g/min) did not provide a large satiety response as well, even though they did provide one fifth of the daily energy. This is in line with a large body of evidence showing that consuming sugar-sweetened beverages contributes to a positive energy balance and may even lead to weight gain[16-19]. Removing these foods from the diet would therefore seem a promising strategy in the struggle against obesity, which has indeed been proven effective in a study where reducing sugar-sweetened beverages resulted in weight loss[20].

Another interesting observation is that the foods with the lowest eating rate (g/min) were the largest source of protein and carbohydrates. This was expected, because the more macronutrients present in a food, the less water it contains, and the more chewing is necessary before a bite can be swallowed, which decreases eating rate. However, fat seems to be an exception, because the foods from the second category provided larger amounts of fat than foods from the first category. So we propose that fat does not exert the same inhibiting effects on eating rate as protein and carbohydrates do. In fact, this is in line with a previous finding, where no association was found between eating rate of foods and fat content, whereas protein and carbohydrates were negatively associated with eating rate[9].

Foods with a high eating rate in kJ/min can be ingested quickly and simultaneously provide energy. We found that food intake was mostly determined by foods that had either a low (slow calories) or a high (fast calories) eating rate. Despite equal food intakes, actual energy intake did differ largely, where foods with fast calories provided most of the daily energy intake (37%). There is sufficient evidence to assume that when foods are ingested quickly, they have a low satiety response[2,9,18,21-23]. Because foods with fast calories probably do not provide a large satiety response and because they clearly contribute largely to our current energy intake, reducing their intake may proof useful in reducing total daily energy intake. This should be confirmed in future studies.

Taste is an important food characteristic that drives our food intake. This follows from our innate preferences for sweet taste and rejections for bitter and sour tastes[24]. We have a preference for sweet and salty or savoury foods, because these tastes signal nutrients which are essential for our metabolism, whereas we have an aversion to bitter and sour foods, because these tastes rather serve as a warning to avoid ingestion. We indeed found that food intake originating from sweet foods was very high, as was expected[25], which stresses the finding that our diet is becoming increasingly sweet[6]. The high intake of bitter foods was surprising, but could mainly be explained by the high intake of coffee and tea and some alcoholic beverages. These foods contain stimulating or relaxing compounds, like caffeine and alcohol, which makes it attractive to consume these foods, despite of their tastes.

Food intake from salty/savoury foods was relatively low, with ca. 350 g, whereas the energy intake from these foods was high (25%), indicating the large energy density of salty/savoury foods (Table 2.3). A large part of this energy originated from fat; in fact, salty/savoury foods were the largest source of the total fat intake. This was surprising, considering the observation that we tend to have a preference for sweet, high-fat foods[26-28]. Apparently, intake of salty/savoury, high-fat foods is greater, at least in the studied population, suggesting a preference for these foods.

The considerable proportion of foods that can be ingested quickly, foods that provide fast calories and sweet foods to the current diet appear to reflect major changes in the diet, compared to the diet of our ancestors. Most likely, this diet contained hardly any foods that provided energy and could simultaneously be ingested quickly[2]. Similarly, sweet tasting foods were rare[1]. These changes in the current diet may be partly responsible for the high prevalence of obesity. This is supported by the increases in obesity prevalence in non-Western societies which are subject to nutrition transition[29]. In these societies, the original diet is changing towards a diet high in fats, sugars and refined foods, but low in fibre content; changes that entail changes in the eating rate and taste of the foods[30, 31]. And with these changes in the diet, obesity becomes a serious health problem, suggesting a causal relation.

As is often the case in assessing food intake, subjects tend to underreport their food intake[32]. Underreporting in the National Food Consumption Survey, 2003 (ca. 11% of energy intake) is similar as found in other studies using 24h dietary recalls[33, 34]. In the present analyses, we excluded potential underreporters, using a cut-off value of EI/BMR of 1.35[13]. After excluding underreporters, the energy intake in our data seemed biologically plausible. Nevertheless, underreporting may still be present, which may have applied particularly to specific food groups, like snacks[35]. Simultaneously, foods with a healthy image, like fruit and vegetables may have been overreported[36].

A consequence of our exclusion of underreporting is that we drastically reduced the variance in BMI, because subjects with a high BMI showed lower EI/BMR ratios. The study population had therefore a relatively healthy BMI and comparisons between normal-weight and overweight subjects were not possible. It would be worthwhile to overcome the problem of underreporting, particularly in overweight individuals, e.g. by using the doubly labelled water technique or to observe actual food intake with cameras, and to compare food intake according to eating rate or taste of foods between normal weight and obese individuals.

Another limitation is that the division of foods into eating rate categories was based on the eating rates of only 45 food items, rather than on actual measurements. Many of the food items in the Food Composition Table were comparable with one of the 45 food items. There were, however, also several food items that did not show any resemblance to any of the 45 food items, which hindered an accurate estimation of the food's eating rate. For these foods, we therefore had to estimate eating rate based on food characteristics like viscosity and temperature, which may have resulted in the over- or underestimation of the eating rate. But in order to reduce the risk of misclassifying foods into a wrong eating rate category, we limited the number of categories to four, two for mainly solid foods, one for semi-solid foods and one for liquid foods. To obtain more precise estimations of a food's eating rate, it is required to measure the eating rate of many more foods.

In conclusion, we have demonstrated that most of the energy intake originated from sweet foods (34%), followed by neutral (30%) and salty/savoury (25%) foods. In addition, we observed that a considerable amount of the daily energy intake originated from foods that can be ingested very quickly (18% of total energy intake, originating mainly from energy yielding liquids) and even more from foods with fast calories (37% of total energy intake, originating from foods like desserts, savoury snacks and processed meats). Assuming that this energy induces a limited satiety response, consuming such foods may easily contribute to a positive energy balance. These new insights into our food pattern suggest that the current diet has changed considering the eating rate and taste of the foods. In order to investigate whether these changes in the diet are associated with obesity, it is recommended to compare food consumption data between BMI subgroups in large populations, using data that are less prone to underreporting.

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Appendix: Rules used to classify foods according to eating rate (g/min) and taste

Eating rate

1. Boiled, baked or fried potatoes in category 1, mashed potatoes in category 2
2. Raw vegetables in category 1, cooked vegetables in category 2
3. Fruit in category 2, fruit on syrup or pureed fruit in category 3
4. Unprocessed meats and fish in category 1, processed meats and fish in category 2
5. Bread, cookies and pastries in category 1; breakfast cereals in category 2
6. Spreads (sweet like chocolate paste and savoury like cream cheese) in category 2
7. Dairy depending on the viscosity and temperature: ice-creams in category 1; puddings in category 2; yoghurts, custards and porridges in category 3; milk and yoghurt drinks in category 4
8. Nuts, chips and candy in category 1
9. Soups & bouillons in category 2
10. Fats, oils & sauces in category 2, salad dressings in category 1
11. Non-alcoholic cold drinks in category 4; non-alcoholic hot drinks in category 3; alcoholic drinks depending on their alcohol content: category 4 (<5g alcohol/100g), category 3 (5–15g alcohol/100g) or category 2 (>15g alcohol/100g)

Taste

1. Boiled potatoes are neutral; baked potatoes, fried potatoes and mashed potatoes are salty/savoury
2. Vegetables are sweet (corn, carrots etc.), sour (tomatoes, pickles etc.), bitter (cabbages, spinach, sprouts etc.) or neutral (cucumber, beans, broccoli etc.)
3. Fruit is sweet, except citrus fruits and apples, which are sour
4. Meat and fish are salty/savoury
5. Breads and cereals are neutral; sugar sweetened breads and cereals are sweet
6. Cookies, pastries and candy are sweet
7. Cheese and savoury spreads are salty/savoury
8. Dairy is sweet (milk, sweetened desserts), sour (unsweetened yoghurts and quarks) or neutral (unsweetened porridges, like rice porridge)
9. Nuts and chips are salty/savoury
10. Soups and bouillons are salty/savoury
11. Sauces are sweet (barbecue sauce, etc.), salty/savoury (sate sauce, cheese sauce, etc.) or sour (dressings/vinegar); gravy is salty/savoury; fats and oils are neutral
12. Soft drinks and lemonades are sweet; pure fruit (orange and apple) juices are sour; coffee and tea are bitter; alcoholic drinks are sweet (liqueurs) or bitter; water is neutral

3

Taste – nutrient relations in commonly consumed foods

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Abstract

Taste is expected to represent a foods' nutrient content. The objective was to investigate whether taste acts as nutrient-sensor, within the context of the current diet, which is high in processed foods. Intensities of the five basic tastes of 50 commonly consumed foods were rated by 19 subjects (aged 21.0 (SD 1.7) y, BMI 21.5 (SD 2.0) kg/m^2). Linear regression was used to test associations between taste and nutrient contents. Food groups based on taste were identified using cluster analysis; nutrient content was compared between food groups, using ANOVA. Sweetness was associated with mono- & disaccharide (R^2 = 0.45, P < 0.01). Saltiness and savouriness were correlated, with r = 0.92 (P < 0.01) and both were associated with sodium (both: R^2 = 0.33, P < 0.01) and protein (R^2 = 0.27, P < 0.01 and R^2 = 0.33, P < 0.01, respectively). Cluster analysis indicated four food groups: neutral, salty & savoury, sweet-sour and sweet foods. Mono- & disaccharide content was highest in sweet foods (P < 0.01). In salty & savoury foods, protein content (P = 0.01 with sweet-sour foods, n.s. with neutral or sweet foods) and sodium content (P < 0.05) were highest. Associations were more pronounced in raw and moderately processed foods, than in highly processed foods. The findings suggest that sweetness, saltiness and savouriness signal nutrient content, particularly for simple sugars, protein and sodium. In highly processed foods, however, the ability to sense nutrient content based on taste seems limited.

Introduction

Sensory properties from foods are important in the regulation of food intake. In theory, people learn to associate sensory properties from foods with the metabolic consequences of ingesting these foods[1, 2]. As a result of this learning, sensory properties give rise to expectations about foods, and they become signals, which drive subsequent food selection[3, 4].

Sensory signals mainly originate from the taste, smell, texture and vision. First of all, these signals inform us whether a particular item is indeed a potential food. So the evaluation of these signals serves as a primary gatekeeper to identify what we are about to ingest[5]. Next, when the item is identified as a food, these signals, and taste in particular, are expected to represent some of the foods' components[6]. Bitter tastes, for example, may signal toxic compounds, whereas sourness may signal a low pH or unripe foods[6, 7]. Similarly, it is assumed that a sweet taste signals the carbohydrate and energy content, whereas a savoury taste signals the protein content[8]. This latter suggests that taste serves as a nutrient sensor. Clearly, however, not all nutrients are signalled through taste. Most vitamins and minerals, for example, have no obvious association with taste, although these components are essential for health. So far, it seems that taste in its function as nutrient sensor mainly serves as a signal for macronutrients, with carbohydrates and proteins in particular, and sodium, which are essential for human survival on short term.

To our knowledge there are no data available, showing that there is indeed a link between taste and nutrient content. Especially in our current food environment, where up to 60% of all consumed foods is highly processed[9], sensory signals may not be in accordance anymore with the nutrient content, due to technological processes. These technological processes are applied for instance to enhance palatability by adding flavours and aromas, or to reduce energy content by using fat replacers or non-nutritive sweeteners, without changing sensory properties. The discrepancy between sensory signals and nutrient content that may occur because of these technological processes would then undermine the predictive power of the sensory signals[10]. As such, this may affect food intake regulation.

The objective of this study was to investigate associations of taste with the nutrient content of commonly consumed foods. This provides knowledge on whether we can still rely on taste as a signal for nutrient content within the context of our current food environment.

Subjects and Methods

Design

Subjects rated the intensity of the five basic tastes (sweetness, saltiness, savouriness, sourness, and bitterness) of 50 commonly consumed foods. The five tastes were rated in separate sessions. So in one session, the sweetness of all 50 foods was rated; in another session the saltiness of all foods was rated, and so on. The tastes were tested in a random order for each subject. In addition, the order in which food items were tested within a session was ad random as well. This study was conducted according to the guidelines laid down in the Declaration of Helsinki. Written informed consent was obtained from all subjects, who received financial compensation for their participation.

Subjects

Men and women, aged 18 – 35 y, were recruited in Wageningen. Potential subjects were screened with a questionnaire to determine whether they met the following inclusion criteria: they had a BMI of 18,5 – 25 kg/m^2, were in good physical and mental health, did not smoke, and were not pregnant or lactating. Subjects who had food allergies or disliked the foods they had to test were excluded. In total, 4 men (aged 20.8 (SD 1.5) y, BMI 21.4 (SD 2.2) kg/m^2) and 15 women (aged 21.1 (SD 1.8) y, BMI 21.6 (SD 2.1) kg/m^2) participated in the study. The PROP status of each subject was established using a method described elsewhere[11-13]. In total, there were 7 super tasters,10 normal tasters, and 2 non-tasters.

Foods

The 50 food items used in this study were selected to represent a range of commonly consumed foods within the Netherlands, using the National Food Consumption Survey, 2003[14]. This survey contains several food groups and from each relevant food group (fats and oils, alcoholic drinks, and herbs, spices and sauces were not considered), we selected those foods that were often consumed. We were careful to select foods that were normally consumed at breakfast, lunch, dinner, and between meals. Twenty-eight of the 50 food items were those items that were most often consumed within their food group, 7 foods were the second most and 6 foods were the third most often consumed foods within their food group. In addition, the items were consumed by a mean of 45.5% (SD 21.3%) of the users of the food group the items belong to. So, for example, the food group 'potatoes' had in total 752 users and of these 752 users, 454 users consumed boiled potatoes. This means that 60.4% of the users of the food group 'potatoes' consumed boiled potatoes.

The foods were grouped according to their level of processing into "highly processed" (n = 35) or "raw and moderately processed" (n = 15) using the definition of Slimani *et al* (2009)[9]. An exception to this definition is roasted, unsalted peanuts, which we considered as moderately processed, comparable with boiled potatoes, while Slimani *et al.* considered peanuts as highly processed. Raw and moderately processed foods were grouped together because of the low number of food items in these categories.

Experimental procedure

We used the Spectrum Method[15] to obtain an anchored rating of the taste intensity of sweetness, saltiness, savouriness, sourness and bitterness for the 50 food items. Subjects evaluated the taste intensity of a food item according to 5 reference solutions for each taste. These reference solutions contained increasing concentrations of sucrose for sweetness, sodium chloride for saltiness, monosodium glutamate (MSG) for savouriness, citric acid for sourness, and caffeine for bitterness, dissolved in demineralized water. The actual concentrations we used and the taste intensity it represents on a scale of 0 – 15 are shown in **Table 3.1**. The taste intensity of the reference solutions was indicated on the serving cups.

Table 3.1 Concentrations of the reference solutions and the perceived taste intensity of the reference solutions, judged by 19 subjects.*

	Sweetness	Saltiness†	Savouriness	Sourness	Bitterness
Concentration‡					
Taste intensity					
0	Su: 0.0	NaCl: 0.0	MSG: 0.0	CA: 0.0	Caff: 0.0
2	Su: 0.058	NaCl: 0.034	MSG: 0.059	CA: 0.0026	Caff: 0.0026
5	Su: 0.146	NaCl: 0.051	MSG: 0.207	CA: 0.0052	Caff: 0.0041
10	Su: 0.292	NaCl: 0.094	MSG: 0.414	CA: 0.0078	Caff: 0.0077
15	Su: 0.467	NaCl: 0.120	MSG: 0.887	CA: 0.0104	Caff: 0.0103
Perceived intensity§					
Taste intensity					
5	7.5 (2.2)	3.8 (2.2)	6.1 (2.6)	8.0 (3.2)	4.8 (2.2)
10	10.7 (2.1)	6.2 (3.6)	7.6 (2.4)	10.1 (3.1)	6.4 (3.1)

*Su, sucrose; NaCl, sodium chloride; MSG, monosodium glutamate; CA, citric acid; Caff, caffeine

†For saltiness, intensity ratings are 0, 2.5, 5, 8.5, 15

‡Data are shown as mol/l

§Data are shown as mean (SD), ratings were made on a scale of 0 – 15

Because there were no reference solutions available for MSG/savouriness, we developed a psychophysical function (perceived taste intensity vs. concentrations of MSG). First, subjects rated the taste intensity of the reference solutions of sucrose and sodium chloride to familiarize them with intensity ratings. Then, to create the actual psychophysical function, the subjects tasted in a random order 30 solutions of MSG, with concentrations ranging from 0 – 0.887 mol/l (or 0 – 15 weight/weight%). Ratings on taste intensity were made on a scale of 0 – 20. The MSG concentrations that corresponded most with an intensity rating of 2, 5, 10, and 15 (actual ratings were 2.0 (SD 1.6), 5.4 (SD 4.4), 9.8 (SD 4.2), and 15.3 (SD 3.3)) were selected for the reference solutions.

Before the actual food items were evaluated, subjects first participated in 2 training sessions to get acquainted with the testing procedure and the evaluation of taste intensities in mixed solutions and in food items, other than the 50 test food items. In the second training session, the intensities of the reference solutions with defined intensities of 5 and 10 were rated by the subjects as well, as a measure of the performance of the subjects (Table 3.1).

The 5 sessions in which the taste intensities of the 50 food items were rated, lasted for one hour and took place at the same time of day for each subject. Subjects were instructed to consume their habitual breakfast and lunch on the day of a test session and to refrain from eating or drinking anything else than water one hour before the start of a session, to standardize appetite ratings. During a session, the 5 reference solutions were tasted first, which were then available throughout the entire session. Then, subjects placed the food item in the mouth, tasted and expectorated the sample, compared the intensity with the reference solutions and rated the taste intensity on a scale from 0 – 15. Before and after each food item was tested, subjects neutralized their mouth with a cracker and by rinsing with demineralized water. Ca. 10 g of each food item was offered.

Data analyses

The mean intensity ratings of the food items were calculated and used in the analyses. The content of macronutrients (g/100g), dietary fibre (g/100g), and sodium (mg/100g) were based on the Dutch Food Composition Table of 2006[16]. Total flavonoid content was based on the Dutch Food Composition Table of 1995[17].

Analyses were performed using SAS version 9.1.2 (SAS Institute Inc. 2004, Cary, NC, USA). Simple and multiple regression analyses were performed using PROC REG to test associations of taste intensity ratings with nutrient content. The nutrient content was treated as the independent variable and the intensity ratings or taste patterns were treated as the dependent variable. In the simple regression analyses, food items were left out of the analyses in case these food items did not contain the independent variable of interest. So for example when foods did not contain any fat, these foods were not considered in the analyses with fat content as the independent variable. Data were analysed for all food items together and separately for the level of processing. To investigate whether the associations between nutrient content and taste intensity depended on the PROP status of subjects, analyses were also performed separately for PROP status. Because there were no differences in the associations according to PROP status, these data are not shown.

In addition, a cluster analysis was performed using PROC CLUSTER to identify groups of food items, based on the five taste intensities. Ward's method was used to form clusters and the pseudo t^2 was used to estimate the number of clusters. As such, 4 main clusters were identified, which accounted for 71% of the variance ($R^2 = 0.71$). The advantage of the cluster analysis is that the 5 tastes are considered together, as they occur in different combinations within foods, and not as independent from each other. Next, ANOVA was performed using PROC GLM to investigate differences in nutrient content between the identified clusters or food groups. Tukey's test was used for post hoc analyses. *P*-values < 0.05 were considered significant.

Results

Sweetness

The intensity ratings of sweetness and saltiness are shown in **Figure 3.1**. A positive association was found between sweetness and mono- & disaccharide content, with $\beta = 0.16$ ($P < 0.01$) and $R^2 = 0.45$, n = 41. The association was stronger in the raw and moderately processed foods, with $\beta = 0.36$ ($P < 0.01$) and $R^2 = 0.71$, whereas in highly processed foods the association was less pronounced, with $\beta = 0.15$ ($P < 0.01$) and $R^2 = 0.42$ (**Figure 3.2**). An inverse association was found between sweetness and protein content, with $\beta = -0.12$ ($P = 0.04$) and $R^2 = 0.09$, n = 47. This association was only significant in highly processed foods, with $\beta = -0.19$ ($P = 0.04$) and $R^2 = 0.14$, not in the raw and moderately processed foods (Figure 2). Within the highly processed foods, sweetness was best predicted by both mono- & disaccharide and protein content, with $\beta = 0.16$ ($P < 0.01$) for mono- & disaccharide content and $\beta = -0.15$ ($P = 0.02$) for protein content, with $R^2 = 0.55$ for the total model.

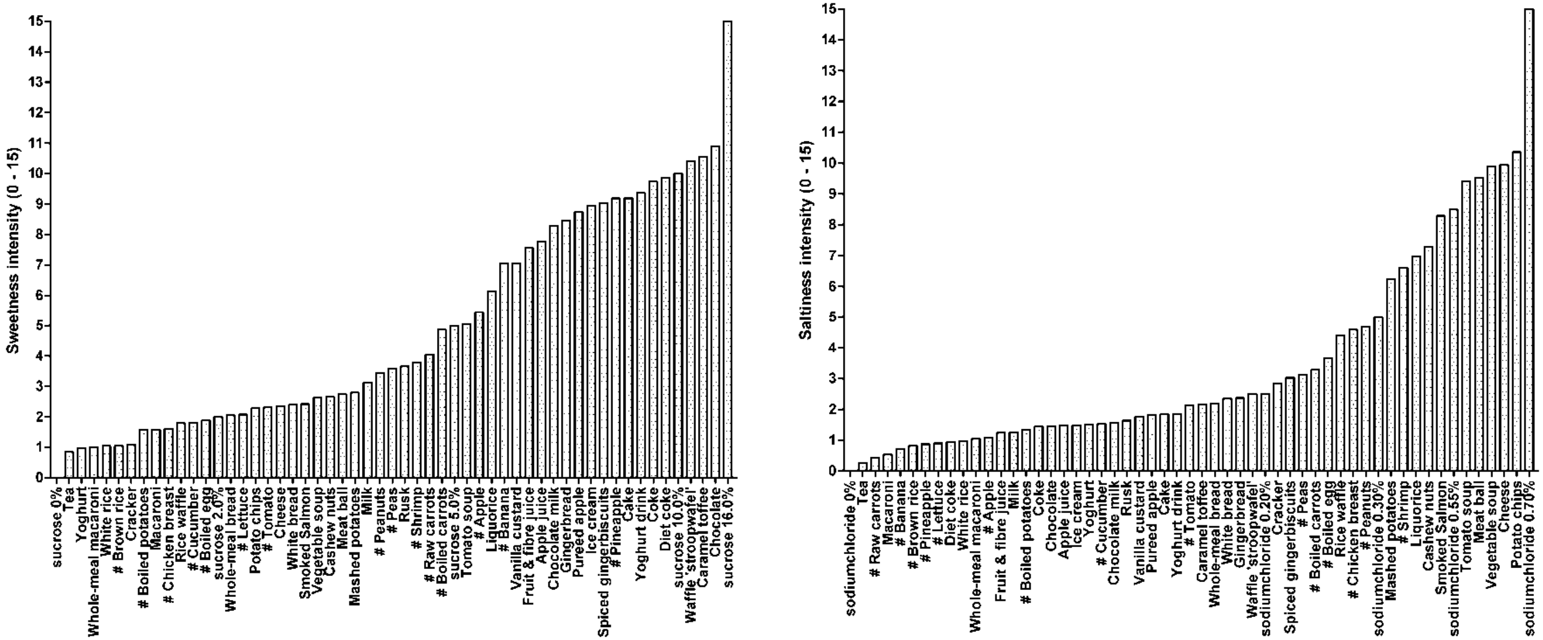

Figure 3.1 *The mean sweetness and saltiness intensity ratings of 50 food items and the 5 reference solutions. Food items indicated with an # are considered as raw or moderately processed foods.*

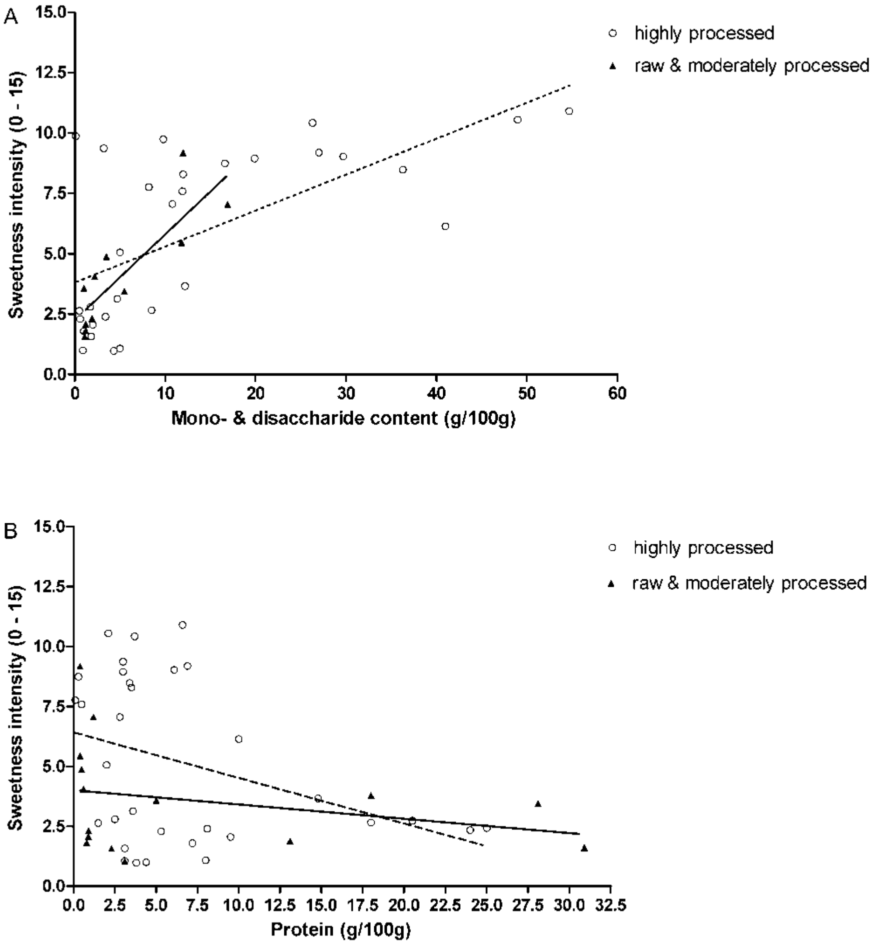

Figure 3.2 *The associations between sweetness and mono- & disaccharide content (A, with R^2 = 0.71 (P < 0.01) for raw and moderately processed foods (black line), and with R^2 = 0.42 (P < 0.01) for highly processed foods (dotted line)) and the associations between sweetness and protein content (B, with no significant association for raw and moderately processed foods (black line), and with R^2 = 0.14 (P = 0.04) for highly processed foods (dotted line)).*

Saltiness

Saltiness was positively associated with sodium content, with β = 0.0062 ($P < 0.01$) and R^2 = 0.33, n = 49. In raw and moderately processed foods, the association was stronger, with β = 0.0051 ($P < 0.01$) and R^2 = 0.51 (**Figure 3.3**). In highly processed foods, the association was less pronounced, with β = 0.0064 ($P < 0.01$) and R^2 = 0.29. Saltiness was also positively associated with protein content with β = 0.19 ($P < 0.01$) and R^2 = 0.27, n = 47. The association was stronger in raw and moderately processed foods, with β = 0.14 ($P < 0.01$) and R^2 = 0.63 (Figure 3.3). In highly processed foods, the association was less pronounced, with β = 0.25 (*P* < 0.01) and R^2 = 0.27. Saltiness was best explained by a model containing both independent variables, only in the raw and moderately processed foods. In this combined model, with R^2 = 0.90, sodium content had a regression coefficient of β = 0.0039 (*P* < 0.01) and protein content of β = 0.11 (*P* < 0.01).

Savouriness

In general, all food items were rated low on savouriness intensity: 28 food items were rated below an intensity of 2, and 16 items were rated between 2 and 5. The

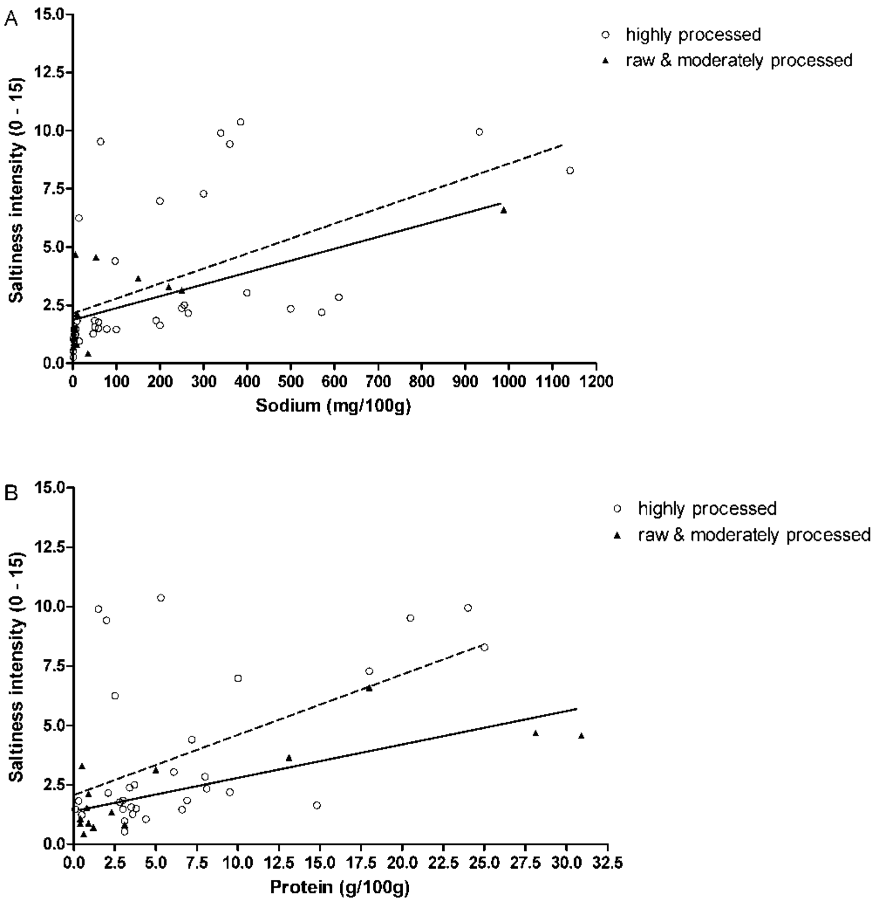

Figure 3.3 *The associations between saltiness and sodium content (A, with R^2 = 0.51 (P < 0.01) for raw and moderately processed foods (black line), and with R^2 = 0.29 (P < 0.01) for highly processed foods (dotted line)) and the associations between saltiness and protein content (B, with R^2 = 0.63 (P < 0.01) for raw and moderately processed foods (black line), and with R^2 = 0.25 (P < 0.01) for highly processed foods (dotted line)).*

remaining 6 food items (potato chips, smoked salmon, tomato soup, meatball, vegetable soup, and cheese) were rated between 5 and 10. No food items were rated above an intensity rating of 10. Savouriness was strongly correlated with saltiness, with r = 0.92 ($P < 0.01$). Savouriness was positively associated with sodium content, with β = 0.0043 ($P < 0.01$) and $R^2 = 0.33$, n = 49. Similar results were obtained with analyses separately for the level of processing, with β = 0.0032 ($P = 0.02$) and $R^2 = 0.37$ for raw and moderately processed foods and β = 0.0049 ($P < 0.01$) and $R^2 = 0.34$ for highly processed foods (**Figure 3.4**). Savouriness was also positively associated with protein content with β = 0.15 ($P < 0.01$) and $R^2 = 0.33$, n = 47. In raw and moderately processed foods, the association between protein content and savouriness was stronger, with β = 0.11 ($P < 0.01$) and $R^2 = 0.64$ (Figure 4). In highly processed foods, the association was less pronounced, with β = 0.19 ($P < 0.01$) and $R^2 = 0.31$. Savouriness was best explained by a model containing both independent variables, only in the raw and moderately processed foods. In this combined model, with $R^2 = 0.80$, sodium content has a regression coefficient of β = 0.0023 ($P < 0.01$) and protein content of β = 0.09 ($P < 0.01$).

Sourness

The majority of the food items were not considered as sour: 34 items were rated below an intensity of 2 and 10 items were rated between 2 and 5. From the remaining food items, 5 were rated between 5 and 10 (pineapple, yoghurt drink, fruit & fibre juice, apple juice, and apples), while only 1 item (yoghurt) was considered as very sour, with a rating above 10. Sourness was inversely associated with carbohydrate content, with β = -0.04 ($P < 0.01$) and $R^2 = 0.20$, n = 44. Considering the type of carbohydrates, we found that it was mainly the polysaccharide content that was responsible for the association, with β = -0.032 ($P = 0.01$) and $R^2 = 0.19$ (n = 32). This association was only significant in highly processed foods, with β = -0.04 ($P < 0.01$) and $R^2 = 0.25$.

Bitterness

None of the food items were considered as bitter, with 32 items rated below an intensity of 2 and the other 18 items between 2 and 5. An inverse association was found between bitterness and carbohydrate content, with β = -0.018 ($P < 0.01$) and $R^2 = 0.24$ (n = 44). Considering the type of carbohydrates, we found that it was the polysaccharide content that was inversely associated with bitterness, with β = -0.014 ($P = 0.03$) and $R^2 = 0.15$ (n = 32). When analysing the data separately for level of processing, there were no significant associations anymore between polysaccharide content and bitterness intensity. In addition, no associations were found between bitterness and flavonoid content of foods.

Cluster analysis: food groups

The cluster analysis indicated 4 main clusters or food groups, based on the taste intensities of the foods: cluster 1 (‘*neutral foods’*) contained mainly foods without a predominant taste; cluster 2 (‘*salty & savoury foods’*) contained foods with high saltiness and savouriness intensities; cluster 3 (‘*sweet-sour foods’*) contained foods with high sweetness and sourness intensities; and cluster 4 (‘*sweet foods*’) contained foods that were only rated high on sweetness intensity (**Table 3.2**). When comparing

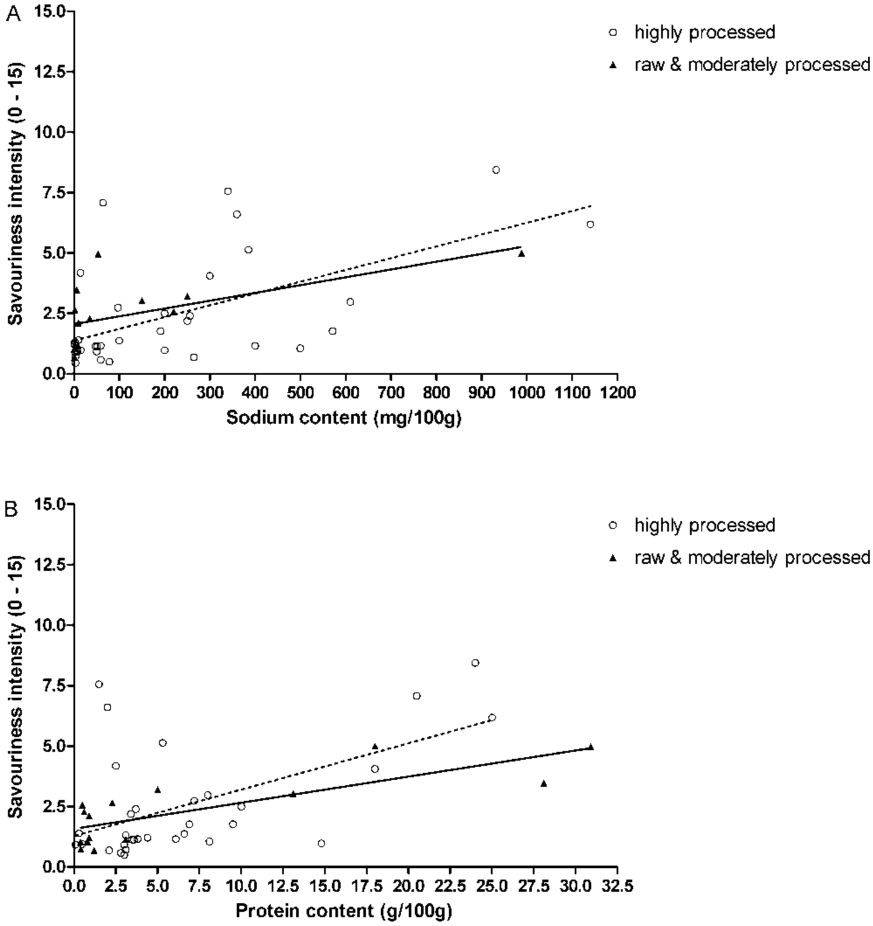

Figure 3.4 *The associations between savouriness and sodium content (A, with R^2 = 0.37 (P = 0.02) for raw and moderately processed foods (black line), and with R^2 = 0.34 (P < 0.01) for highly processed foods (dotted line)) and the associations between savouriness and protein content (B, with R^2 = 0.64 (P < 0.01) for raw and moderately processed foods (black line), and with R^2 = 0.31 (P < 0.01) for highly processed foods (dotted line)).*

the nutrient content between the 4 food groups, this revealed that mono- & disaccharide content of the *'sweet foods'* was significantly higher than the other food groups (*P* < 0.01) (Table 3.2). In addition, protein content was highest in the *'salty & savoury foods'*, which was significantly different from the *'sweet-sour foods'* (*P* = 0.01), but not from the *'neutral foods'* and the *'sweet foods'*. Sodium content of the *'salty & savoury foods'* was significantly higher than the other food groups (*P* < 0.01 for *'neutral foods'* and *'sweet & sour foods'* and *P* = 0.02 for the sweet foods).

Table 3.2 Food groups, assessed with cluster analysis using the 5 taste intensities, and their mean taste intensity ratings and nutrient composition*

	Neutral foods (n = 25)		Salty & savoury foods (n = 6)		Sweet-sour foods (n = 9)		Sweet foods (n = 10)	
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*
Taste intensity†								
Sweetness	2.5[a]	1.3	2.9[a]	1.1	7.6[b]	2.9	8.9[b]	1.4
Saltiness	2.8[a]	2.2	9.6[b]	0.7	1.4[a]	0.4	1.9[a]	0.7
Savouriness	2.3[a]	1.3	6.8[b]	1.1	0.9[c]	0.3	1.2[c]	0.7
Sourness	1.3[a]	0.9	2.4[a]	1.3	6.6[b]	2.5	1.2[a]	0.5
Bitterness	1.7[a]	1.1	1.7[a]	0.8	2.3[a]	0.5	1.3[a]	1.0
Nutrient content‡								
Fat	6.2[a]	13.9	16.0[a]	14.5	0.3[a]	1.0	13.2[a]	11.3
Carbohydrates	23.8[a,b]	26.9	11.6[b]	19.7	9.0[b]	5.2	44.8[a]	24.5
Mono-disaccharides	4.0[a]	8.2	1.0[a]	2.0	8.7[a]	5.2	28.3[b]	14.8
Polysaccharides	19.8[a]	23.6	10.6[a]	19.8	0.3[a]	0.7	16.6[a]	16.2
Protein	7.9[a,b]	8.4	13.1[a]	11.3	0.9[b]	1.4	3.9[a,b]	1.9
Sodium	171[a]	251	537[b]	409	17[a]	22	165[a]	127

[a,b,c] Values within a row with unlike superscript letters were significantly different ($P < 0.05$)

*Foods in the *'neutral foods'* cluster were brown and white rice, (whole-meal) macaroni, egg, rice waffle, whole-meal and white bread, cucumber, lettuce, mashed and boiled potatoes, cashew nuts, shrimps, milk, rusk, boiled and raw carrots, peas, crackers, chicken breast filet, peanuts, tomato, tea, and liquorice. Foods in the *'salty & savoury foods'* cluster were meat ball, vegetable and tomato soup, smoked salmon, potato chips, and cheese. Foods in the *'sweet-sour foods'* cluster were pineapple, yoghurt, yoghurt drink, (diet) coke, (pureed) apple, apple juice, fruit & fibre juice. Foods in the *'sweet foods'* cluster were banana, custard, chocolate, chocolate milk, toffee, waffle, ginger biscuits, ice cream, cake, and gingerbread

†Data represent taste intensity ratings on a scale of 0 - 15

‡Data are shown as g/100g, except for sodium, which is shown as mg/100g

Discussion

In this study we investigated the associations of taste with the nutrient content of commonly consumed foods. We found that a large part of sweetness could be explained by the mono- & disaccharide content. In addition, both saltiness and savouriness were associated with sodium and protein content. In line with these observations, the analyses that were performed on the four identified food groups indicated that sweet foods, which formed a separate food group, had a high mono- & disaccharide content, and that the salty and savoury foods, which formed another food group, had a high protein and sodium content. These observations point towards a nutrient sensing function of a sweet, salty and savoury taste for the simple sugars, protein and sodium. The lack of clear associations between nutrient content and a bitter and sour taste may indicate that these tastes have other functions than to signal the presence of nutrients. Because these tastes are often associated with toxins or compounds with a low pH, these tastes, particularly at high intensities, may rather serve as a warning to avoid ingestion, and to prevent illness or damage to the body[6,7].

The taste system is a guardian of the human body, which should predict how an item would affect the body: does it provide nutrition or will it cause illness[5]. But it is not only a matter of deciding whether or not to actually ingest a food. For instance, it has been demonstrated that when protein intake is low, we tend to increase protein intake, to prevent a shortage[18]. This suggests that we are not only capable of identifying an item as a food, but we are even capable of estimating the macronutrient content of foods. Our data now confirm that mono- & disaccharides, protein, and sodium, which are essential for health, are indeed linked with the taste system, suggesting that we should be capable of estimating the presence of these nutrients in foods, based on their taste. Although not investigated in the present study, it should be mentioned that the taste system is likely not sufficient in regulating the intake of all essential nutrients: many micronutrients for instance have no clear taste qualities and appear not to be linked with the taste system. To nevertheless ensure a sufficient intake of these essential nutrients, other regulatory mechanisms may be operating in the body. One such system is the occurrence of sensory specific satiety, which is responsible for a variety seeking behaviour, leading to a nutritionally varied diet[19].

The observed associations between taste and nutrient content were systematically more pronounced in the raw and moderately processed foods than in the highly processed foods. Although this needs to be confirmed in future studies, this suggests that within highly processed foods, the ability to sense nutrient content based on taste is more limited compared to within raw and moderately processed foods. The smaller associations in highly processed foods may result from technological processes, which are applied to increase palatability, to reduce energy content or to preserve foods. The use of additives can provide foods with additional tastes, which may suppress other tastes[20,21]. Particularly sweetness appears to be the dominant taste, which suppresses other tastes. Ice cream or chocolate, for example, can contain a large amount of sodium chloride (195 mg/100g and 250 mg/100g, respectively, whereas for example mashed potatoes contain ca. 190 mg/100g) without having a salty taste, because of its sugar content. This suppressive effect on tastes may potentially be harmful, if we cannot adequately recognize the nutrient content. The suppressive effect on saltiness, for example, may lead to high intakes of sodium chloride, which may have adverse effects on blood pressure[22].

At this time, we do not know to what extent the associations between taste and nutrient content influence food intake regulation. One can imagine that the predictability of a sensory signal gets compromised when for example sweetness is followed by the delivery of carbohydrates at some, but not all occasions[10]. This may ultimately force us to rely on other signals to determine our food intake[23]. So far, however, consuming foods with non-nutritive sweeteners or fat replacers has been demonstrated to reduce energy intake[24-27], although not all studies could demonstrate such an effect (for reviews, see[28-30]). Nevertheless, this may indicate that we are rather successful in deceiving our regulatory system and that we still base our food intake on sensory signals, whether they are appropriate or not. This can simultaneously have adverse consequences on energy intake, when for example the fat content of foods is covertly high, which has been shown to increase energy intake[31]. It remains to be investigated what it means for the regulation of food intake when more and more foods provide sensory signals that do not represent the nutrient content.

This study demonstrated that savoury taste was not only associated with protein, which was expected, but also with sodium. The high correlation we observed between salty taste and savoury taste (r = 0.92) suggests that either these tastes occur side-by-side or that subjects were not able to clearly distinguish between a salty and a savoury taste. This latter seems surprising, considering the clear distinction between taste receptors for salt (Na+ channels) and MSG (G-protein coupled receptors)[32,33]. Another possible explanation for the correlation between salty and savoury taste is that MSG, which is supposed to represent a true savoury flavour, also contains sodium, which may have increased the perceived salty taste intensity. It should therefore be confirmed whether savouriness truly signals sodium content, preferably with other compounds than MSG as reference, or that the observed association rather reflects the inability to discriminate savouriness from saltiness.

Because there are indications that there is a taste component in signalling fat[34], we considered collecting data on fatty taste. The difficulty with fat is that this macronutrient has no clear taste quality[35], but can exert very diverse oral sensations, ranging from creaminess to crunchiness. It is therefore very hard to obtain standardized intensity ratings of a fatty taste for different foods. In addition, it is not clear yet whether subjects would be capable of judging a fatty taste, irrespective of textural aspects[36]. It was therefore decided not to collect data on fatty taste, within the current study.

It should be mentioned that we excluded foods from the simple regression analyses in case the foods did not contain the nutrient of interest. In case of sweetness this means that foods sweetened with non-nutritive sweeteners, that did not contain simple sugars, but did have a sweet taste, were not considered in the analyses. In this case there was only 1 product, diet coke, that was sweetened with non-nutritive sweeteners. Excluding this one product would not have influenced the observed association to a great extent. Including all 50 foods (so also non-sweet foods without simple sugars) would result in an explained variance of 0.47 instead of the observed 0.42.

There are some limitations to this study. The performance of our subjects was somewhat limited, as can be seen in Table 3.1. Because we saw an increase in performance over the training sessions, additional training sessions would have been necessary to train our subjects more adequately. The implications for our results are nevertheless limited, because the effects of this performance on taste intensity ratings would likely be similar for each food item. We therefore do not think that this would have changed the associations between taste intensity and nutrient contents. Another limitation is that besides taste, there are also other sensory properties that may be involved in signalling the nutritious contents of foods, like texture and smell. These properties were not studied here, although they might have explained additional variation in our data. It should also be mentioned that our findings depend on the foods we selected. But because we took great care of selecting foods that are often consumed in the Netherlands, where 82% of the foods were in the top 3 of most often consumed foods within their food group, we nevertheless think that our findings accurately represent the situation as it occurs in everyday life.

In conclusion, the observed associations between taste and nutrient content suggest that a sweet, salty and savoury taste serve as a signal for the nutrient content of a food, particularly for simple sugars, proteins and sodium. In highly processed foods, the associations between taste and nutrient contents were less pronounced than in raw or moderately processed foods. This suggests that within highly processed foods, the ability to sense nutrient content based on taste is limited. Nevertheless, considering the fact that taste perception not only depends on the nutrient content, but also on other food properties, like the physical structure of foods[37], we consider the explained variances we observed as reasonable and we therefore suggest that, within our total food pattern, we are capable of estimating the nutrient content of foods, particularly the simple sugars, protein and sodium. It is important to consider though, that on product level, there can still be a large discrepancy between nutrient content and taste intensity, as can be seen in food items like ginger biscuits and bread, which are relatively high in sodium content, but low in salty taste intensity.

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4

Hidden fat facilitates passive overconsumption

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Abstract

Food intake regulation may be disturbed when sensory signals from foods are disconnected from their metabolic properties. Consumption of high-fat, energy-dense foods may stimulate passive overconsumption, because these foods do not provide sensory signals in accordance with the actual nutrient content. We examined the effects of perception of fat on energy intake in adults after overfeeding (Study 1) and on energy intake during a meal (Study 2). In study 1, 57 participants consumed 6 mandatory lunches, differing in energy level (100, 200, and 300% of a standard lunch intake) and fat condition (visible fat and hidden fat). Ad libitum energy intake was measured during subsequent meals. In Study 2, 51 participants consumed 2 lunches that were high in visible or hidden fats. We measured ad libitum energy intake during lunch. In Study 1, the energy intake at dinner was 8% higher in the hidden fat condition than in the visible fat condition (P = 0.0046). A main effect was also found for the energy level of the lunch (P < 0.0001), with highest intake following the 100% energy level and lowest intake following the 300% energy level. In Study 2, the energy intake was 9% higher in the hidden fat condition than in the visible fat condition (P = 0.013). Perception of fat influences energy intake. In the presence of visible fats, energy intake was lower than in the presence of hidden fats, suggesting that hidden fats may contribute to overconsumption. Appropriate sensory signals may be important in preventing overconsumption.

Introduction

Foods provide sensory signals through taste, texture, smell, sight and sound. These signals are linked with the post-ingestive consequences of foods[1-4]. In this way, people learn to expect certain satiety values based on the sensory signals of foods. However, in the present food supply, the sensory signals are often disconnected from their original nutritional consequences. For instance, people have difficulty identifying foods as being high in fat[5,6]. Products like cakes and pastries have a high fat content, but they lack the sensory properties that are normally attributed to fat, such as creaminess and crispiness[7]. This may imply that people are unable to recognize the true nutrient content, due to inappropriate sensory signals.

The consequence of this disconnection between sensory and metabolic signals is that consumption of high-fat and energy-dense foods may not lead to adequate adjustments in food intake[8-11]. Consumption of such foods stimulates passive overconsumption, predisposing people to becoming overweight. Several experimental studies have shown that after overfeeding, in many cases people do not adjust their energy intake adequately to maintain energy balance[12-15]. This indicates an inability to detect a high energy intake, which may result from sensory signals that are not in accordance with the actual nutrient content of the food.

Until now, it has to our knowledge remained uncertain whether the intake of high-fat foods that do provide more appropriate sensory signals would indeed be lower, and therefore would play a potential role in preventing overweight, than the intake of similar foods without these sensory signals. In Study 1, we investigated the effects of a fixed lunch either high in visible or hidden fats on subsequent dietary compensation. In Study 2, we investigated the effects of the sensory perception of fat on the ad libitum energy intake during the meal itself.

Subjects and Methods

Subjects

Participants were recruited using flyers and mailing lists. In both studies, we included men and women aged 18 – 30 y with a BMI of 20 – 23 kg/m^2 who ate breakfast on a daily basis (**Table 4.1**). Exclusion criteria were restraint eating, based on the Dutch Eating Behaviour Questionnaire [males > 2.90, females > 3.40[16]]; weight change of > 1 kg during the last 6 mo; lack of appetite; smoking; following an energy restricted diet; and suffering from any metabolic, endocrine, or gastrointestinal disorder. Weight-stable individuals with a normal BMI were selected in order to study dietary compensation in a situation where the regulation of food intake is likely to be accurate. All participants gave their written informed consent. The Ethics Committee of Wageningen University approved the study protocols. Participants in both studies were not informed about the true purpose of the studies. Instead, they were told that the study aimed to identify aspects that influence the palatability of meals. Study 1 began with 64 participants. Seven participants stopped because of poor compliance, participation was too much of a burden, or because of personal reasons. The final sample consisted of 57 participants. Study 2 consisted of 51 participants who were not involved in Study 1. There were no drop-outs.

Study design

Study 1

Participants visited Wageningen University on 6 days, separated by at least 48 h, to consume a mandatory test lunch and an ad libitum dinner and breakfast the next morning. The experiment used 3 x 2 conditions of the lunches in a randomized cross-over design. Lunches varied in energy content (3 levels) and fat condition (2 levels).

Study 2

Participants in Study 2 visited the university twice, with a minimal wash-out period of 48 h, to consume an ad libitum lunch. This study had a randomized cross-over design. The 2 lunches varied in fat condition (2 levels).

Test meals

Study 1

Lunch. Lunch consisted of 3 energy levels: 100, 200, and 300% of the energy intake of a standard lunch, which is ~ 22% of the daily energy intake [18]. This daily intake was based on the individual energy requirement, calculated by the basal metabolic rate (BMR) and the physical activity level [17]. Physical activity level was estimated by a retrospective questionnaire. BMR was estimated by the following equation:

$$\text{BMR (MJ)} = 0.064 \times \text{kg} + 2.84 \text{ (males)}$$
$$\text{BMR (MJ)} = 0.0615 \times \text{kg} + 2.08 \text{ (females)}.$$

For logistical reasons, 3 energy groups were formed based on the individual energy requirement (< 11 MJ; 11 – 13 MJ; > 13 MJ).

Within each energy level, the fat condition of the lunches varied. The main focus was the visibility of fat, but because it was not possible to vary just the appearance of foods, other sensory properties, like texture and taste, varied as well. Because visibility was most important, the fat conditions were labelled visible fat and hidden fat. Macronutrient composition of the lunches were similar. To create the fat conditions, we manipulated foods or selected specific products suitable for that condition (**Table 4.2**). We accurately calculated the macronutrient and fatty acid content of each lunch in advance, based on the Dutch Food Composition Table[19]. To check for the actual composition, we performed chemical analyses (**Table 4.3**).

Dinner. Dinner consisted of a main course and a dessert. We served either curly kale stew, fried rice, or macaroni. For dessert, we offered chocolate, vanilla, or caramel custard. The courses were offered in portion sizes twice the amount normally consumed during dinner[18] to ensure ad libitum consumption. The courses did not differ in palatability, as rated by the participants (*P* = 0.21). Energy density was similar for each course (0.49 MJ/ 100 g).

Table 4.1 Subject characteristics of the participants in Study 1 and Study 2[1].

Characteristics	Study 1 (n = 57)	Study 2 (n = 51)
Men, *n*	15	9
Women, *n*	42	42
Age, *y*	21.3 ± 2.2	22.0 ± 2.6
BMI, kg/m^2	21.9 ± 1.2	21.7 ± 1.4
PAL[2] [17]	1.9 ± 0.2	1.8 ± 0.1
BMR[3], *MJ* [17]	6.4 ± 0.7	6.1 ± 0.7
Dietary restraint score[4]	2.2 ± 0.6	2.3 ± 0.7

[1] mean ± SD, all such values
[2] PAL, physical activity level
[3] MBR, basal metabolic rate
[4] Assessed with the Dutch Eating Behaviour Questionnaire[16]

Table 4.2 Food products used during lunch in Study 1[1]

Visible fat lunch		Hidden fat lunch	
Food product	**Amount**	**Food product**	**Amount**
Tomato soup, *g*	60	Tomato soup, *g*	70
Skimmed milk, *mL*	90	Skimmed milk, *mL*	110
Wholegrain bread, *g*	35	Wholegrain bread, *g*	35
Bun, *g*	20	Croissant, *g*	20
Sausage in puff pastry, *g*	40	Meat roll, *g*	30
Margarine, *g*	10	Margarine, *g*	5
Chocolate butter, *g*	12	Chocolate spread, *g*	10
French cheese, *g*	10	Strawberry jam, *g*	15
Vanilla custard, *g*	50	Vanilla custard & cream, *g*	40
Whipped cream, *g*	8		
Total, *g*	335	**Total, *g***	335

[1] Data are shown for the medium energy requirement group, in the 100% energy level. Food products consumed in 200% energy level were twice the amounts shown in this table, in the 300% energy level intake was three times these amounts

Snacks. Participants received several sweet and savoury snacks for the evening, all of which were commercially available in standardized packages of 1 portion size. No other snacks were allowed. Participants had to provide drinks themselves, but alcohol was not allowed.

Breakfast. Breakfast was presented buffet-style. Customary breakfast products were offered in standardized portion sizes and were marked to enable us to measure how much of each product was consumed.

Study 2

The lunches consumed in Study 2 varied in fat condition: a visible and a hidden fat condition. Lunches were offered in 3 courses to mimic a customary Dutch meal: tomato soup, sandwiches, and a dessert. The energy density of the courses was calculated in advance and chemical analyses were performed to check for actual energy density (**Table 4.4**).

Questionnaires

In both studies, participants rated their hunger, fullness, appetite, appetite for something sweet, appetite for something savoury, prospective consumption, and thirst on a 10-point scale ranging from 'not at all' to 'extremely', at several moments during a test day. They were also asked to rate the palatability and the perceived fatness of each meal and its courses after an initial taste on a 10-point scale.

Procedure

During the study period of both studies, participants were asked to maintain a normal level of physical activity and to consume their normal breakfast before 9.00h on the morning of a test day. After breakfast, and until the test lunch, participants were asked to refrain from eating. Only water, coffee, or tea (without milk or sugar) was allowed. Every meal was served in the dining room of the university. Participants were divided throughout the room in such a way that any interaction between the participants was minimized. They were instructed not to talk to each other to reduce the effects of presence of others on food intake. During the meals, there was no interaction except with the researchers, when they gave instructions and served meals.

Table 4.3 Macronutrient composition of the lunches used in Study 1 for the visible and hidden fat conditions[1].

	100% Energy level		**200 % Energy Level**		**300% Energy level**	
Nutrients	Visible fat	Hidden fat	Visible fat	Hidden fat	Visible fat	Hidden fat
Energy, *MJ*	2.9	2.6	5.6	5.5	8.2	7.8
Energy density, *MJ/100g*	0.86	0.78	0.84	0.82	0.82	0.78
Total fat[2], *En%*	54.2	48.8	54.2	52.1	53.6	50.0
SFA, *En%*	18.2	11.0	18.8	14.6	17.7	12.3
MUFA[3], *En%*	17.8	19.6	17.5	20.1	17.3	20.3
PUFA, *En%*	20.8	16.2	15.3	15.0	15.9	15.6
Total carbohydrates, *En%*	35.4	41.8	35.1	38.0	36.0	40.1
Total proteins, *En%*	10.2	9.7	10.6	10.1	10.6	9.7

[1]Data shown for the medium energy requirement group, as determined through chemical analyses

[2] En%, Energy per cent

[3] MUFA, monounsaturated fatty acids

Table 4.4 Energy density of the food products used in Study 2.

Food products	Visible fat condition	Hidden fat condition
Tomato soup[1]	0.54	0.54
Sandwich[2]	0.64	0.69
Vanilla custard[1]	0.48	0.49

[1] Values presented as MJ/100g, as determined through chemical analyses
[2] Values presented as MJ per sandwich, as determined through chemical analyses

Study 1

Lunch started at 12.30h. Participants received instructions about the study protocol. Before and after lunch, at 14.00h, 15.00h and 16.00h, and before and after dinner, appetite parameters had to be rated. Participants were instructed to finish the entire lunch. After lunch, they left the laboratory and returned again at 17.15h when dinner was served. Participants were asked to refrain from eating in the afternoon; only water, coffee, and tea, without milk or sugar was allowed. During dinner, participants were instructed to eat until they were comfortably full. They received snacks after dinner to take home for the evening and were instructed to eat the snacks ad libitum, to bring back leftovers, and to report consumption of beverages in a diary. Breakfast the next morning was served at 8.00h, and participants were again instructed to eat until they were comfortably full.

Study 2

Lunches were served at 12.30h. Participants were instructed to rate appetite parameters before lunch and after each course and to eat from all 3 of the courses until they were comfortably full. Participants were given 10 min to consume the soup and the dessert and 15 min for the sandwiches. We introduced these timed sessions so participants took their time to eat from each course.

Energy intake

The amount of food and drink consumed during the dinner (Study 1) and lunch (Study 2) was weighed to the nearest 1.0 g. The energy and macronutrient intake was calculated by the Dutch Food Composition Table and adjusted for the chemical analyses. We measured the consumption in the evening by checking the leftover snacks and the diary with the recorded beverage intake. The consumption during breakfast was measured by counting each consumed breakfast items. We calculated the energy intake based on these consumption data and the Food Composition Table.

Data analysis

For data analysis, we used the SAS version 9.1.2 (SAS Institute). Variables on energy intake (MJ) and the ratings of appetite (scale 1 – 10) are presented as means ± SEM unless stated otherwise. In Study 1, the energy intake during dinner, in the evening, during breakfast the next morning, and the palatability and fat perception were compared between the 3 energy levels and the 2 fat conditions. This was done by an ANOVA. The energy level and fat condition and the interaction term were fixed factors;

participants were treated as a random factor. Tukey's test was used for post hoc analyses. The dietary compensation was calculated as the predicted energy intake if no compensation occurred following overconsumption minus actual energy intake divided by the extra energy ingested in the 200% and 300% energy levels, compared with the intake in the 100% energy level[20]. In Study 2, the energy intake, palatability and fat perception were compared by means of a paired comparisons *t* test. To adjust for palatability of the meals, we added these ratings to the model as covariates.

For the ratings of appetite, we performed a repeated-measures ANOVA and included time and fat condition and the interaction terms as fixed factors and participants as a random factor. In Study 1 , the energy level and the accompanying interaction terms were included as fixed factor as well. To adjust for baseline ratings, we added these to the model as covariates. P values < 0.05 were considered significant.

Results

Study 1

Lunches in Study 1 were rated significantly different for fat perception, indicating that manipulation of the fat condition was successful. The palatability of the lunches differed significantly as well (**Table 4.5**).

Energy intake

Fat condition affected ad libitum energy intake during dinner, whereby intake after the hidden fat condition was 7.8% higher than after the visible fat condition ($P = 0.0046$) (**Figure 4.1**). Energy intake during dinner differed between all 3 energy levels of the lunch (all $P < 0.0001$). After correcting for the palatability of the lunch, energy intake still differed between energy levels ($P < 0.0001$) and fat conditions ($P = 0.0052$). Dietary compensation after the 200% level was 19% in the visible fat and 15% in the hidden fat condition. Following the 300% level, compensation was 23% in the visible fat and 21% in the hidden fat condition.

Table 4.5 Perceived fatness and palatability of the lunches in Study 1 and Study 2 for the visible and hidden fat conditions[1].

	Perceived fatness			**Palatability**		
	Visible fat	Hidden fat	*P*-value[2]	Visible fat	Hidden fat	*P*-value[2]
Study 1 (n = 57)						
Lunch	8.5 ± 0.17	6.5 ± 0.21	<0.001	6.2 ± 0.26	7.1 ± 0.24	<0.001
Study 2 (n = 51)						
Total lunch	6.8 ± 0.15	5.3 ± 0.20	<0.001	6.8 ± 0.15	6.8 ± 0.14	0.63
Soup	8.5 ± 0.25	4.3 ± 0.26	<0.001	6.2 ± 0.28	6.9 ± 0.26	0.048
Sandwich	7.2 ± 0.22	5.3 ± 0.19	<0.001	6.3 ± 0.19	6.4 ± 0.16	0.83
Dessert	7.1 ± 0.24	6.4 ± 0.34	0.075	8.0 ± 0.25	7.0 ± 0.31	0.0028

[1] Data are presented as mean ± SEM, on a 10-point scale

[2] *P*-values presented for differences between the visible fat and hidden fat conditions

In the evening, participants consumed most energy from beverages and the provided snacks in the 100% energy level (2.39 ± 0.19 MJ for the visible fat and 2.26 ± 0.18 MJ for the hidden fat condition). This was followed by the 200% level (2.17 ± 0.18 MJ for the visible fat and 2.27 ± 0.20 MJ for the hidden fat condition) and the 300% level (1.63 ± 0.18 MJ for the visible fat and 1.53 ± 0.16 MJ for the hidden fat condition). The 100% and 300% levels ($P < 0.0001$), and the 200% and 300% levels ($P < 0.0001$) differed from one another. Fat conditions did not differ.

Energy intake at breakfast following the 100% level was 2.35 ± 0.11 MJ for visible fat and 2.36 ± 0.10 MJ for hidden fat. In the 200% level, the intake was 2.24 ± 0.12 MJ for the visible fat and 2.32 ± 0.11 MJ for the hidden fat condition. In the 300% level, intake was 2.31 ± 0.12 MJ and 2.16 ± 0.10 MJ for the visible and hidden fat condition, respectively. Energy intake did not differ between energy levels or fat conditions.

Participants showed additional dietary compensation in the evening and during breakfast. In the 200% energy level, dietary compensation was increased to 32% in the visible fat condition and 17% in the hidden fat condition. In the 300% energy level, compensation was 37% and 38% in the visible and hidden fat condition, respectively. There was a main effect of energy level ($P < 0.0001$); the differences between fat conditions did not reach significance ($P = 0.077$).

Ratings of appetite

The 6 lunches resulted in clear differences in all appetite ratings. Here, we only show the results of fullness, because the other parameters show similar results. Fullness differed between all 3 energy levels (all $P < 0.0001$) (**Figure 4.2**). Fullness was higher after the visible fat condition than after the hidden fat condition ($P = 0.0012$). A significant time x energy level interaction was observed ($P = 0.0075$), where fullness in the 200% and 300% level increased more after lunch, and did not return to baseline, compared to the 100% level.

Study 2

Lunches in Study 2 were rated significantly different for fat perception (Table 5). When looking at the 3 courses separately, we found that the soup and sandwiches differed significantly in fat perception, whereas the difference in the desserts did not reach significance. The mean palatability of the 2 lunches (comprising all courses) was similar. The palatability of the soup and the dessert did, however, differ significantly between fat conditions (Table 4.5).

Energy intake

Taking the 3 courses together, participants consumed 9.2% more energy in the hidden fat condition than in the visible fat condition ($P = 0.013$) (**Figure 4.3**). When we examined the 3 courses separately, we found a significant difference in only the first course, with an intake of 746.2 ± 55.9 kJ in the visible fat condition and 1180.8 ± 72.8 kJ in the hidden fat condition ($P < 0.0001$). The results did not change after correcting the energy intake for the palatability of the courses, with energy intake differing only in the first course ($P < 0.0001$). Energy intake in the second course ($P = 0.13$) and in the third course ($P = 0.11$) did not differ between fat conditions.

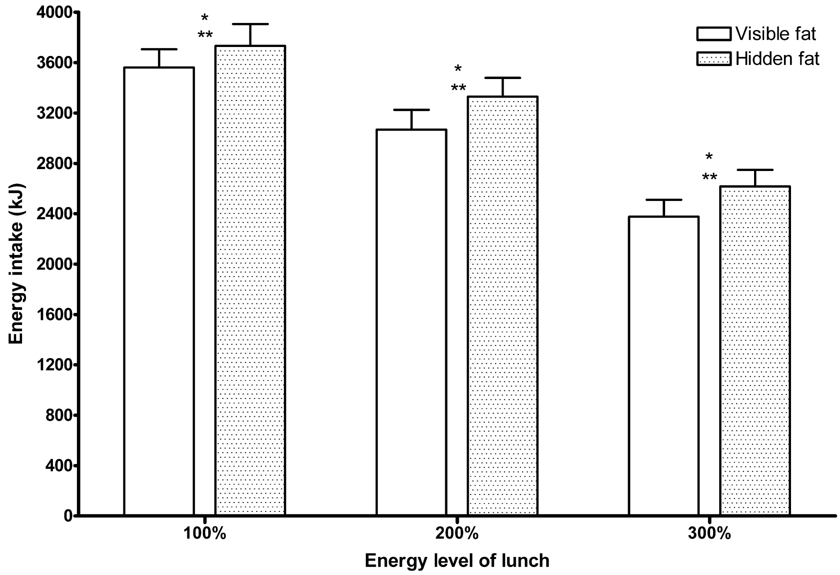

Figure 4.1 *Ad libitum energy intake during dinner following lunch with energy level 100, 200, or 300% and a visible or hidden fat condition in young adults (Study 1). Data are means ± SEM, n = 57. * Different between fat conditions, P = 0.0046 (main effect). ** Different between the 3 energy levels, P < 0.0001 (main effect).*

Ratings of appetite

Fullness in both fat conditions increased during lunch (*P* < 0.0001) (**Figure 4.4)**. Fullness was lower in the visible fat condition than in the hidden fat condition, which was significantly different only after the first course was consumed (*P* = 0.0021). A significant time x fat condition interaction was observed (*P* = 0.016), where participants felt more full in the hidden fat condition, especially after the soup was consumed. After the lunch was finished, fullness was similar in both conditions, even though the energy intakes differed between the fat conditions.

Discussion

The studies presented here showed that the ad libitum energy intake of a meal high in visible fats was significantly lower than the intake of a meal with hidden fats. In addition, we found that after overconsumption during lunch, people partially compensated for the extra energy ingested. Subsequent energy intake was lower after a lunch high in visible fats than after a lunch high in hidden fats. This indicates that food intake was influenced by fat perception.

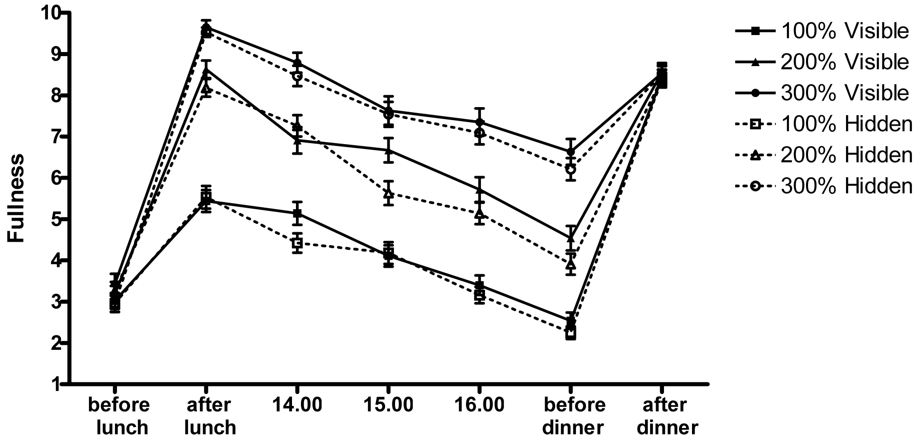

Figure 4.2 *Fullness following a lunch with energy level 100, 200, or 300% and a visible or hidden fat condition in young adults (Study 1). Data are mean ± SEM, on a 10-point scale, n = 57, starting before lunch and continuing until after dinner. Main effects were found for energy level (P < 0.0001), fat condition (P = 0.0012) and time (P < 0.0001). There was a significant time x energy level interaction (P = 0.0075).*

Figure 4.3 *Ad libitum energy intake during lunch in the visible or hidden fat condition in young adults (Study 2). Data are means ± SEM, n = 51. * Different between the fat conditions, P = 0.013*

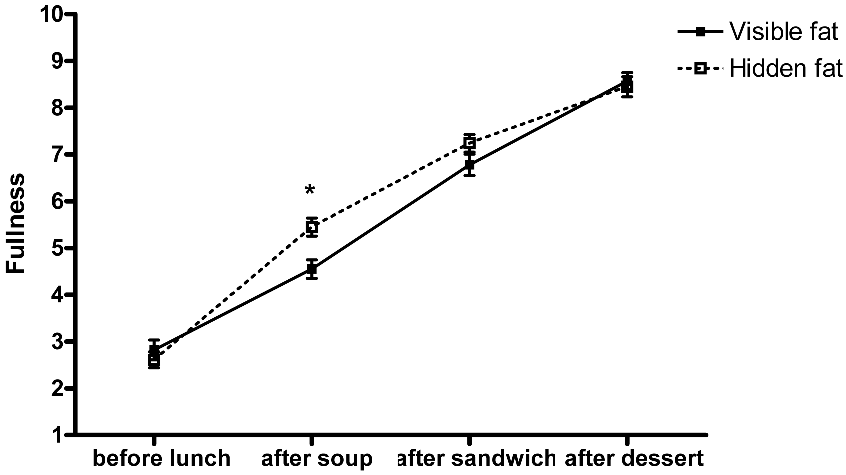

Figure 4.4 *Fullness during lunch following the visible or hidden fat condition in young adults (Study 2). Data are means ± SEM, on a 10-point scale, n = 51. * Different in fat condition, only after the soup, P = 0.0021.*

The selection of the study population needs to be taken into account when generalizing our findings. We selected unrestrained young adults with a BMI of 20 – 23 kg/m^2. Restrained subjects have been shown to be more influenced by the perceived caloric content of foods[21] and by receiving information about the fat content[22] than unrestrained subjects. They therefore may also be more affected by the sensory perception of fat. In addition, the participants had to be in energy balance, so it is likely that the regulation of energy intake was adequate. However, we found that dietary compensation was insufficient. It might be expected that compensation in populations with a less optimal regulatory system, such as overweight people, would be even worse compared with this research population.

The external validity of this study needs to be addressed. In real life, it is not likely that overconsumption will occur in such magnitudes as in the present experiment. The same is true for the fat conditions; the presence of visible or hidden fats will be more subtle and, as such, the influences on food intake will be less pronounced. However, the manipulations needed to be sufficient to investigate the occurrence of dietary compensation and the influences of hidden or visible fat on food intake. Another aspect is that, despite the fact that the amount of food the participants received was based on their individual requirements and that we used customary Dutch food products, it is possible that participants were forced to change their habitual eating pattern due to the study protocol. This may have had differential effects on intake between the hidden and visible fat condition. To what extent the energy intake between fat conditions was influenced by this is unknown. Finally, the experiments were performed in a laboratory. In a free living situation, people may pay less attention to their meals due to distraction[23,24] and may be less sensitive to visible fats. Whether our observations would be detectable outside the laboratory needs further investigation.

Lunches differed in palatability between fat conditions. Such differences may influence (subsequent) energy intake and appetite ratings[25-27]. We therefore corrected the ad libitum energy intake for the palatability of the lunches. This did not affect our results, indicating that our observations were merely the result of differences in fat perception.

In Study 2, the energy intake was higher during only the first course of the hidden fat condition. During the second course, intake did not differ despite differences in fat perception. However, the intake of a course cannot be viewed separately from previous courses. The higher intake during the first course of the hidden fat condition likely reduced the intake in the second course to a greater extent than in the visible fat condition. This may have overridden the effects of fat perception.

Despite accurate calculations of the macronutrient composition of the lunches with the Dutch Food Composition Table[19], chemical analyses revealed some deviations. The data in the composition table are based on commercial products. Several products used in our studies were provided by a local bakery using different recipes, which may have caused the deviations. Small variations in energy intake do not affect subsequent intake[28,29]. Because the differences in composition of the lunches were marginal, we do not think that this influenced the results.

Previously, Davidson and Swithers[4] hypothesized that if the ability to use the sensory signals of food to predict the energetic consequences of intake would deteriorate, this might contribute to overconsumption and subsequent weight gain. The results of our studies support this hypothesis. When sensory signals are disconnected from their metabolic properties (as is the case with hidden fats), people tend to overeat. Food intake may be better regulated, at least in the short term, when the sensory signals are in accordance with the actual nutrient content, as we found in the visible fat condition. Sensory signals may have an influence on food intake through previously learned associations with the post-ingestive consequences[1,30]. This has also been shown in studies that focus on the use of fat replacers, where sensory signals suggest a high fat intake, whereas actual fat intake is low[31-34]. Consumption of these foods did not result in a compensatory increase in food intake, which emphasizes the contribution of sensory signals in the regulation of food intake. This contribution of sensory signals has also been demonstrated in a study, where the intake of soup increased by 73% when the visual signals that enabled people to monitor their intake were partially removed[35]. In our studies, we manipulated the appearance of the foods, but with this manipulation, taste, texture and other sensory signals differed as well. The effects can therefore not be attributed to visual cues alone but rather to a mixture of sensory and cognitive cues. The impact of manipulating just one of the sensory signals or any other food properties on food intake is unknown.

Previously, it has been shown that providing information about the energy or fat content influences food intake[36,37]. This suggests that beliefs people have about foods are involved in food intake. In our studies, the visible fat may have influenced the belief of a high fat intake. It remains unclear whether this effect on energy intake was due to an explicit cognitive process, where participants were truly aware of a high fat intake, or to a more subconscious process initiated through associative learning.

After overconsumption during lunch, participants decreased their energy intake during dinner and in the course of the evening. This contrasts with the results of others, where no compensation was found or only after high levels of overconsumption[12,14]. In these studies, overconsumption was induced by increasing energy density. It has been reported previously that the volume of food affects satiety and energy intake to a greater extent than energy density does[38-40]. In our study, we created overconsumption by increasing the volume of food while keeping the energy density stable. In addition, our study population had an apparently adequate energy regulation. This may explain the dietary compensation we found. This response, however, was not sufficient to fully compensate, at least in the short term. It is possible that energy balance is maintained over a few days rather than during a single day.

Based on our observations, we conclude that the sensory perception of fat does influence food intake. In addition, it is involved in the short-term compensatory response after overfeeding. A question that remains unanswered is to what extent sensory signals of fats are involved in food intake regulation in a free living situation, where sensory signals are less pronounced and mixed with other signals. Considering the current obesity problem, it is worth looking into the effects of sensory signals on food intake regulation and the underlying mechanisms in more detail. This may contribute to the development of strategies to decrease energy intake and prevent weight gain.

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5

Eating rate of commonly consumed foods promotes food and energy intake

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Abstract
We investigated the eating rate of commonly consumed foods and the associations with food intake and macronutrient composition. Ingestion time (s) of 50g of 45 foods was measured to assess eating rate (g/min), after which ad libitum food intake (g) was measured. Thirteen men and 24 women (aged 23.3 (SD 3.4) y, BMI 21.7 (SD 1.7) kg/m^2) participated, each testing 7 foods in separate sessions. We observed large differences in eating rate between foods, ranging from 4.2 (SD 3.7) to 631 (SD 507) g/min. Eating rate was positively associated with food intake (β = 0.55) and energy intake (β = 0.001). Eating rate was inversely associated with energy density (β = -0.00047) and positively with water content (β = 0.011). Carbohydrate (β = -0.012), protein (β = -0.021) and fiber content (β = -0.087) were inversely associated with eating rate, whereas fat was not. This study showed that when foods can be ingested rapidly, food and energy intake is high. People may therefore be at risk of overconsumption, when consuming foods with a high eating rate. Considering the current food supply, where many foods have a high eating rate, long-term effects of eating rate on energy balance should be investigated.

Introduction

In last decades, food availability has shifted from natural, minimally processed foods to highly processed, ready-to-eat foods, characterized by an increase in energy density and a decrease in fibre content[1,2]. In addition, consumption of energy-yielding liquids has increased[3]. This shift coincides with an increased prevalence of obesity, which may imply that these events could be related. Several studies indeed indicate that energy dense, low-fibre diets, and the consumption of energy-yielding liquids are associated with obesity[3-6]. This suggests that ingesting these foods may potentially lead to an increased energy intake.

It has been demonstrated that dietary fibre decreases eating rate[7] and that liquid foods can be ingested more rapidly than solid foods[8]. Accordingly, eating rate may be a mediating factor that explains why ingesting low-fibre foods and energy-yielding liquids would result in an increased intake. Due to a high eating rate, the oral exposure to food, i.e. orosensory exposure, is low. Previous studies demonstrated that a low orosensory exposure is associated with a high food intake[9-12]. When orosensory exposure is low, few signals from the oral cavity may reach the brain, leaving insufficient time for satiety signals to induce meal termination[13]. This may result in a high food intake.

So far, literature on the relation between eating rate and food intake has focused on experimentally manipulated eating rates of single foods[14-18]. No information is yet available on eating rate of a broad range of commonly consumed foods. This information is, however, important in order to estimate the actual contributions of eating rate to total food intake, within the context of our current food environment. In addition, this will enable us to identify food properties that are related to eating rate. The objectives of this study were therefore to investigate the eating rate of commonly consumed foods, to investigate the associations with food and energy intake and the associations with energy density and macronutrient content.

Methods

Subjects

Men and women, aged 18 – 35 y, were recruited by a mailing list, containing subscriptions of people who are interested in participating in consumer research. Potential subjects were screened with a questionnaire to determine whether they met the following inclusion criteria: they had a BMI of 18,5 – 25 kg/m^2, were in good physical and mental health, did not smoke, were not restraint eaters (men > 2.90, women > 3.40 on the Restraint subscale of the Dutch Eating Behaviour Questionnaire[19]), were not following an energy restricted diet, and were not pregnant or lactating. Subjects who had food allergies or disliked the foods that they had to test were excluded. In total, 13 men (aged 21.9 (SD 2.8) y, BMI 22.2 (SD 1.9) kg/m^2, restraint score 1.7 (SD 0.6)) and 24 women (aged 24.0 (SD 3.5) y, BMI 21.4 (SD 1.5) kg/m^2, restraint score 2.5 (SD 0.6)) participated in the study. Each subject tested a total of 7 food items, in separate test sessions. From these 7 food items, two were reference foods (whole-meal bread and yoghurt, see data analyses), which were similar for all subjects. In addition, each subject tested 5 other food items, which were randomly assigned to the subjects. The subjects were informed about the measurement of the ingestion time but they were not aware of the measurement of the ad libitum food intake. All subjects received financial compensation for their participation. The Medical Ethics Committee of Wageningen University approved the study protocol; this study was performed in accordance with the ethical standards laid down in the Declaration of Helsinki. This study is registered in the Dutch Trial Register as NTR1835.

Foods

The food items used in this study were selected to represent a range of commonly consumed foods within the Netherlands, using the National Food Consumption Survey, 2003[20]. This survey contains several food groups and from each relevant food group (fats and oils, alcoholic drinks, and herbs, spices and sauces were not considered), we selected those foods that were often consumed[20]. We were careful to select foods that were normally consumed at breakfast, lunch, dinner, and between meals. The foods represented a range of natural and processed foods, covering a wide range of nutritional, textural and hedonic characteristics. **Table 5.1** provides an overview of the foods used and their macronutrient composition[21].

A power calculation indicated that, with 90% power, foods should be tested by at least 3 subjects to detect a difference in eating rate of 75% between two foods, using an SD between subjects of 29%. The SD was obtained from a pilot study, where eating rate of 27 foods was tested. In addition, this pilot study showed differences in eating rate between foods up to 30 times (3000%), ranging from 10 to 300 g/min. We therefore considered a difference of 75%, equivalent to detecting a difference between 10 and 17.5 g/min, as relevant.

We aimed to have each food item being tested by 6 subjects. However, due to some setback in recruitment, this was not feasible, resulting in an unbalanced design. Because we needed at least 3 observations per food item, the foods with fewer observations (n = 7) were left out of the analyses. The final sample consisted of 45 food items, which were tested by at least 3 and maximum 6 subjects, except for the two reference foods, which were tested 37 times (see Table 5.1).

Experimental procedure

Test sessions were held around lunch time and lasted for 30 min. The 7 test sessions for each subject took place at the same time of day. Subjects were instructed to consume their habitual breakfast on the morning of a test session and to refrain from eating or drinking anything else than water for 3 h before the start of a session, to standardize appetite levels. Consumption of water was not allowed during the last hour before a session. During a test session, subjects were placed in individual booths to exclude interaction with other subjects.

Table 5.1 Commonly consumed foods (n = 45) used to test eating rate and ad libitum food intake, and their nutrient composition.[1]

Food item	Tested by subjects	Serving size[2]	Energy density	Fat	Carbohydrates	Protein	Fiber
	N	*g*	*kJ/100g*	*g/100g*	*g/100g*	*g/100g*	*g/100g*
Boiled potatoes	3	600	325	0	16.8	2.3	3.1
French fries	3	600	1206	8.8	46.0	5.8	3.2
Mashed potatoes	4	600	347	1.6	14.6	2.5	2.5
White rice	4	600	623	0.4	32.7	3.1	0.5
Brown rice	3	600	505	1.4	23.6	3.1	1.4
Boiled carrots	5	500	77	0	4.0	0.5	1.8
Peas	5	500	360	1.0	14.0	5.0	4.7
Cucumber	5	500	34	0	1.2	0.8	0.7
Tomato	3	500	48	0	1.9	0.9	1.3
Carrots raw	3	500	48	0	2.2	0.6	3.0
Lettuce	4	300	36	0	1.2	0.9	0.8
Apple	4	500	207	0	11.8	0.4	2.3
Banana	6	500	375	0.2	20.4	1.2	2.7
Pineapple	3	500	211	0	12.0	0.4	1.2
Meatball	4	400	1127	17.4	8.0	20.5	0
Chicken breast	5	400	667	3.8	0	30.9	0
Boiled egg	3	400	615	10.6	0	13.1	0
Smoked salmon	4	300	838	11.2	0	25.0	0
Tomato soup	5	1000	220	1.0	8.0	2.0	0.7
Vegetable soup	4	1000	90	0.7	2.5	1.5	1.0
White bread	4	400	1101	2.1	52.0	8.1	2.7
Whole-meal bread	37	400	1013	2.3	45.1	9.5	5.1

Table 5.1 (*continued*)

Food item	Tested by subjects	Serving size[2]	Energy density	Fat	Carbohydrates	Protein	Fiber
	N	*g*	*kJ/100g*	*g/100g*	*g/100g*	*g/100g*	*g/100g*
Rice waffle	3	150	1590	2.1	81.7	7.2	4.1
Cracker	3	200	1955	17.0	70.0	8.0	2.2
Potato chips light	6	200	1945	23.1	57.3	6.9	4.7
Chocolate	5	350	2247	32.6	54.7	6.6	0.8
Liquorice	3	350	1479	0	77.0	10.0	0
Caramel toffee	4	350	1872	17.0	71.0	2.1	0
Spiced ginger biscuits	5	500	2052	21.3	68.3	6.1	1.5
Waffle ‘stroopwafel’	3	500	1787	16.0	66.5	3.7	0.4
Gingerbread	4	500	1295	1.2	70.2	3.4	2.5
Cake	5	500	1762	23.9	44.8	6.9	0.6
Cheese	3	300	1561	31.2	0	24.0	0
Peanuts	4	300	2592	52.1	11.0	28.1	7.7
Tea	3	1400	0	0	0	0	0
Milk	5	1400	199	1.5	4.8	3.6	0
Chocolate milk	6	1400	376	3.0	12.2	3.5	0.5
Yoghurt drink	4	1400	128	0	4.5	3.0	1.0
Apple juice	3	1400	141	0	8.2	0.1	0
Diet coke	4	1400	2	0	0.1	0	0
Fruit&fiber juice	5	1400	239	0	13.6	0.5	2
Yoghurt	37	1000	204	1.5	4.5	4.2	0
Vanilla custard	5	1000	393	2.7	14.4	2.8	0
Pureed apple	4	1000	287	0	16.6	0.3	1.4
Ice cream	4	600	910	11.4	25.7	3.0	0.3

[1] Based on the Dutch Food Composition Table, 2006 [21].

[2] Serving size as offered to measure ad libitum food intake.

A test session consisted of two parts: measuring ingestion time and measuring ad libitum food intake. In the first part, subjects received 50g of the food. Foods were offered in standardized, ready-to-eat pieces, if necessary (liquid and semi-solid foods did not require this). Preparation of the samples was done according to a strict protocol in order to standardize the samples, including the serving temperature of warm (65°C) and cold (7°C) food items. Subjects had to press a start button on a computer and immediately start eating or drinking the food in its entirety. They were instructed to ingest the foods at a for them ordinary pace, except for pausing between bites or sips, which was not allowed. After the last bite or sip was swallowed, subjects had to press a stop button. Time needed to consume the 50g, the ingestion time, was measured. In the second part of a session, subjects were offered the same food in a large, pre-weighed amount. The exact amount that was offered, was about 2 times a large portion size. As such, the offered amount differed per food (see Table 6.1). In a pilot study we checked whether the offered amounts were enough to ensure unrestricted consumption. Subjects were instructed to consume the item until they were comfortably full. Actual food intake was measured to the nearest 1.0 g by weighing the leftovers. Water (125 ml) was provided, which had to be drunk in its entirety throughout the second part of the session. Before and after each session, subjects rated appetite parameters on a 9-point scale, ranging from "not …" to "very …". In a separate session, but under similar test conditions, subjects rated palatability of the 7 items that they tested on a 9-point scale ranging from "not …" to "very …".

Data analyses

To reduce the variance in ingestion time due to individual differences, ingestion times were adjusted as follows. The reference products whole-meal bread and yoghurt were used to calculate a subject-specific calibration factor. The ingestion time (s) for the reference products of each subject was divided by the mean ingestion time (s) for the reference products of all subjects (the group mean). Then the mean relative ingestion time for both reference products was calculated for each subject. The inverse of this mean is the individual calibration factor:

1 / [(time to ingest bread {subject} / time to ingest bread {group mean}+ time to ingest yoghurt {subject} / time to ingest yoghurt{group mean}) / 2]

We assumed that, when a subject ingested the reference products faster than the group mean, this subject had a higher eating rate in general, so he or she would tend to ingest all food items faster than the group mean. Ingestion time for all food items that were tested by that subject was, therefore, multiplied by the calibration factor. Whole-meal bread and yoghurt were selected as reference products, because they differ in many food characteristics such as macronutrient composition, fiber content, and viscosity. Ingestion time was therefore expected to differ between these two products. This method reduced the mean between-subject coefficient of variation of ingestion time of all foods from 0.45 to 0.37. The same calibration factor was used to adjust the ad libitum food intake.

Mean eating rate in g/min was calculated based on the mean ingestion time for that food item. Total food intake (g) consisted of both the 50g and the ad libitum

food intake. Energy intake (kJ) was calculated using the Dutch Food Composition Table 2006[21]. Analyses were performed using SAS version 9.1.2 (SAS Institute Inc. 2004, Cary, NC, USA). Simple and multiple regression analyses were used to test associations with PROC REG. To normalize the error distribution, dependent variables were log-transformed in the regression analyses when necessary. To estimate the contribution of each macronutrient and dietary fibre to eating rate, backward multiple regression analyses were used. *P*-values < 0.05 were considered significant.
Because palatability and hunger have previously been shown to influence eating rate and food intake[22-24], we tested whether these variables influenced the eating rate and intake data. No main effects were found of hunger on eating rate or intake. Similarly, no main effect was found of palatability on eating rate, but palatability was positively associated with food intake (β = 44.7 ($P < 0.01$) and $R^2 = 0.22$). Nevertheless, both variables were treated as covariates in the analyses. If they were significant (partial regression coefficients of $P < 0.05$), they were maintained in the final model. In the results, it is indicated where palatability and baseline hunger influenced the associations and thus where the analyses were adjusted for these variables.

Results

The eating rate (g/min) of the foods is shown in **Figure 5.1**. Large differences in eating rate were observed, ranging from 4.2 (SD 3.7) g/min for rice waffles to 631 (SD 507) g/min for diet coke. Eating rate for solid foods ranged from 4.2 (SD 3.7) g/min for rice waffles to 128 (SD 73) g/min for boiled carrots. For semi-solid foods it ranged from 50 (SD 36) g/min for mashed potatoes to 229 (SD 247) g/min for vanilla custard. For liquid foods it ranged from 305 (SD 252) g/min for yoghurt drink to 631 (SD 507) g/min for diet coke. These data indicate that even within a group of foods with comparable characteristics, in this case viscosity, eating rates varied extensively. Another interesting observation was that soups, which can be qualified as liquid foods, were ingested at a rate (67 (SD 29) g/min for vegetable soup and 79 (SD 28) g/min for tomato soup) similar to several solid foods.

Some foods were assessed both in their natural and in a more processed form, to study the effect of processing. Raw carrots had an eating rate of 13.0 (SD 5.1) g/min, whereas boiled carrots had a rate of 128 (SD 73) g/min. Boiled potatoes had an eating rate of 20 (SD 5.4) g/min, whereas mashed potatoes had a rate of 50 (SD 36) g/min. Similarly, raw apples had an eating rate of 53 (SD 43) g/min, whereas pureed apples had a rate of 141 (SD 77) g/min and apple juice had a rate of 619 (SD 69) g/min. These data suggest that processing can increase the eating rate of a food. This does not, however, apply to all processed foods. White bread, for example, was ingested at a lower rate (11 (SD 12) g/min) than was whole-meal bread (18 (SD 21) g/min), although white bread is more processed.

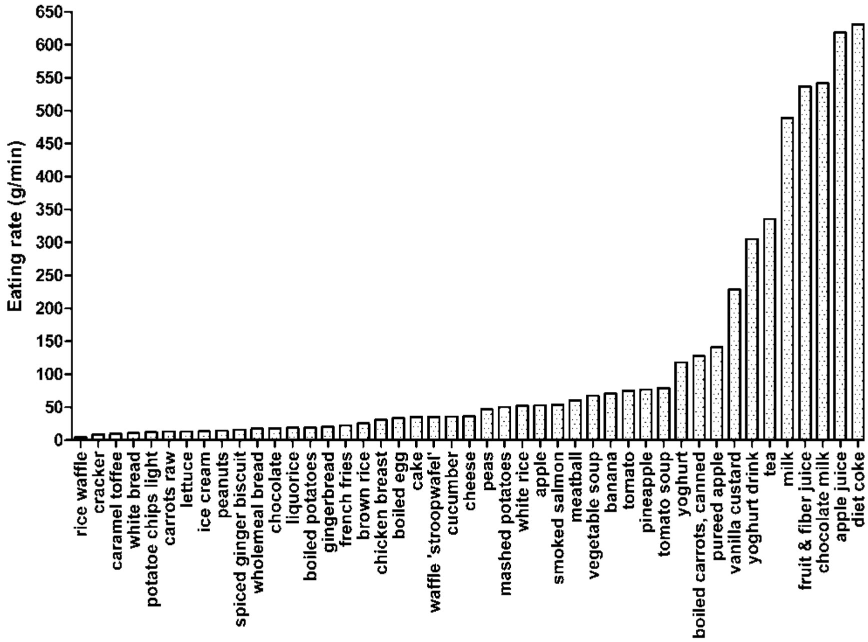

Figure 5.1 *Mean eating rate (g/min) of 45 food items, commonly consumed in the Netherlands.*

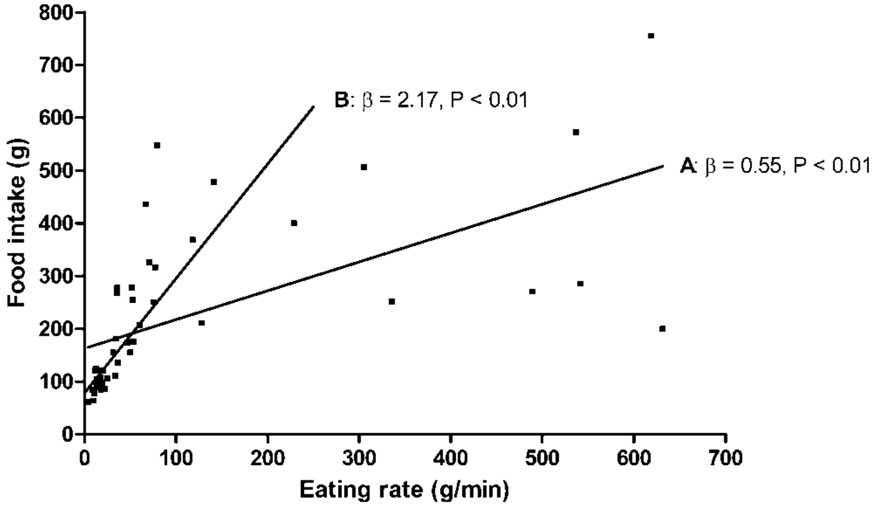

Figure 5.2 *The unadjusted association between eating rate (g/min) and food intake (g) for 45 food items (**A**) and for 33 solid foods (**B**). Regression analysis showed that eating rate was positively associated with food intake (**A**: R^2 = 0.37; **B**: R^2 = 0.55).*

Figure 5.2 shows the association between eating rate (g/min) and food intake (g). A positive association was found, with *β* = 0.55 (*P* < 0.01) and R^2 = 0.37 when all 45 food items were included. After adjusting for palatability, the regression coefficient changed to *β* = 0.49 (*P* < 0.01), with R^2 = 0.50. So for every 10 g/min increase in eating rate, there was an increase in food intake of 4.9g. When we focused on solid foods only (n = 33), excluding the semi-solid and liquid foods from the analyses, we found a positive association between eating rate and intake, with *β* = 2.17 (*P* < 0.01) and R^2 = 0.55. After adjusting for palatability, the regression coefficient changed to *β* = 2.29 (*P* < 0.01) for eating rate and R^2 = 0.62, indicating that for every 10 g/min increase in eating rate, food intake of solid foods increased by 22.9g.

There was a small, but positive association between eating rate and energy intake (log kJ), with *β* = 0.001 (*P* < 0.01) for eating rate and R^2 = 0.54, only after adjusting for energy density. This indicates that for every 10 g/min increase in eating rate, energy intake increased by 1%. Tea and diet coke were left out of the analysis, because these items hardly contain any energy.

To determine which food characteristics influence the eating rate of a food, we performed regression analyses using energy density, water content, macronutrient composition and fibre content. **Figure 5.3** shows the association between energy density (kJ/100g) and eating rate (log g/min), with *β* = -0.00047 (*P* < 0.01) for energy density and R^2 = 0.39. After adjusting for palatability, the regression coefficient changed to *β* = -0.00051 (*P* < 0.01), with R^2 = 0.50. So when energy density of foods increases by 100 kJ/100g, there is a 5.1% decrease in eating rate.

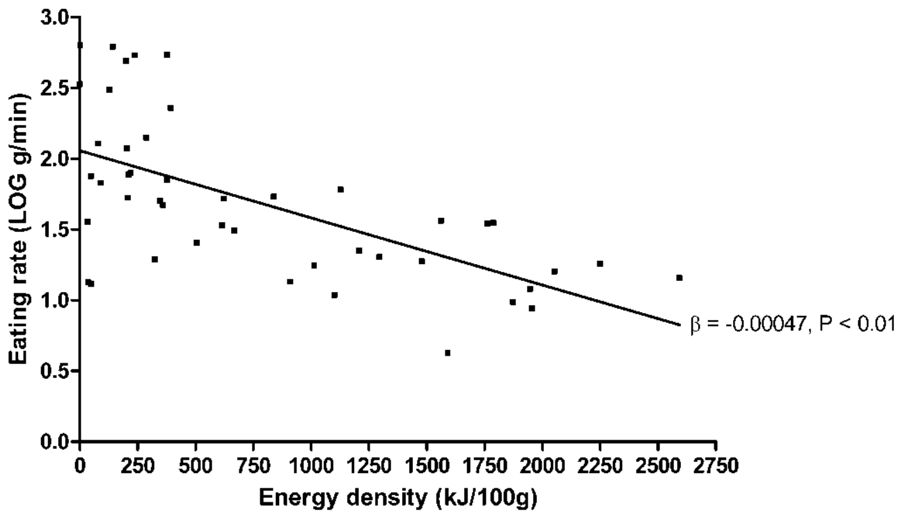

Figure 5.3 *The unadjusted association between energy density (kJ/100g) and eating rate (log g/min) for 45 food items. Regression analysis showed that energy density was inversely associated with eating rate (R^2 = 0.39).*

When investigating the association between energy density (kJ/100g) and food intake (g), as shown in **Figure 5.4**, we found that food intake decreased as energy density increased, with β = -0.11 (P < 0.01) and R^2 = 0.29. After adjusting for palatability and baseline hunger, the regression coefficient changed to β = -0.14 (P < 0.01), with R^2 = 0.64. However, despite of the lower food intake of energy dense foods in grams, actual energy intake (kJ) increased (β = 0.90, P < 0.01 and R^2 = 0.52), as energy density (kJ/100g) increased (**Figure 5.5**). After adjusting for palatability and baseline hunger, the regression coefficient changed to β = 0.82 (P < 0.01), with R^2 = 0.65. These findings suggest that food intake is lower in energy dense foods, but this lower food intake is not sufficient to prevent a higher energy intake.

The water content of foods (g/100g) was positively associated with eating rate (log g/min), with β = 0.011 (P < 0.01) and R^2 = 0.46. After adjusting for palatability, the regression coefficient changed to β = 0.012 (P < 0.01), with R^2 = 0.57. This indicates that when foods contained 10 g/100g more water, the eating rate of these foods increased by 12%.

To identify which macronutrients contributed to the eating rate of foods, we performed multiple regression analyses including fat, carbohydrates, proteins and fibres as independent variables. Carbohydrate content (β = -0.012, P < 0.01), protein content (β = -0.021, P = 0.01) and fibre content (β = -0.087, P = 0.022) were inversely associated with eating rate (log g/min), with R^2 = 0.52. So the eating rate was lower, when foods contained more carbohydrates, protein and/or fibre. Fat content did not contribute significantly to eating rate.

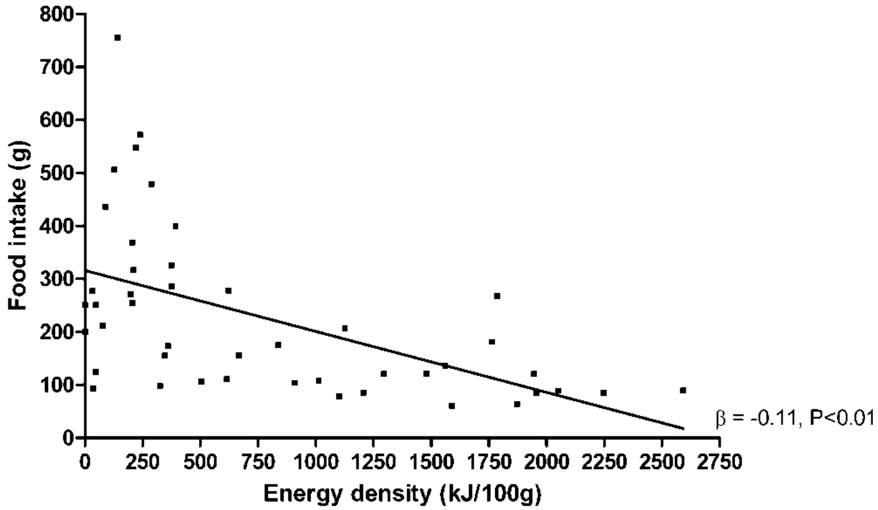

Figure 5.4 *The unadjusted association between energy density (kJ/100g) and food intake (g) for 45 food items. Regression analysis showed that energy density was inversely associated with food intake (*R^2 *= 0.29).*

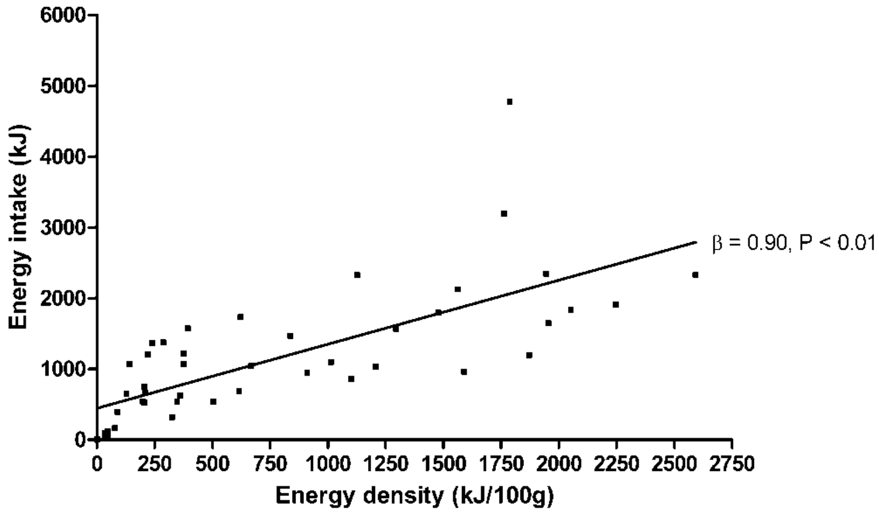

Figure 5.5 *The unadjusted association between energy density (kJ/100g) and energy intake (kJ) for 45 food items. Regression analysis showed that energy density was positively associated with energy intake (R^2 = 0.52).*

Discussion

To our knowledge, this is the first study that investigated eating rates of a range of commonly consumed foods. This study demonstrated large differences in eating rate between foods, where the food with the highest eating rate was ingested almost 160 times as fast as the food with the lowest eating rate. Even within a food category such as solid foods, eating rate between foods differed up to 30 times. In addition, this study demonstrated a positive association between the eating rate of foods and food and energy intake. This is in line with previous work[25,26], where a lower eating rate resulted in lower food and energy intakes. In addition to this previous work, we have now demonstrated the effect across foods, rather than between subjects or within variations of a single food. Within the current food supply, there are many foods available that can be ingested rapidly. Considering the positive association that we found between eating rate and food and energy intake, consuming these foods potentially poses a risk of overconsumption.

Previously, it was demonstrated that viscosity influences food intake[8,27], such that food intake of liquid foods was higher, relative to solid or semi-solid foods, possibly because of a higher intake rate for liquids[9]. The differences that we observed in eating rate between foods are probably the result of differences in food properties, particularly viscosity, with major differences between liquid and solid foods. Soup is, however, an exception. The eating rate of soup, which can be qualified as a liquid, was within the range of solid foods, possibly because soup was consumed with a spoon, or because of its high temperature. Combining this finding with the finding that soup is just as satiating as solid foods[28], we may suggest that eating rate is responsible for the satiating capacity of soup.

Besides viscosity, we particularly focused on the associations of eating rate with energy density, water content and macronutrient composition. We found an inverse association between energy density and eating rate and a positive association between water content and eating rate. When addressing the inverse association between energy density and eating rate, it is important to mention that, despite of a slower eating rate and a lower food intake, the energy intake of energy dense foods was higher than of foods with a low energy density. This is consistent with the observation that daily energy intake is higher when the energy density of the foods consumed is higher[29,30]. So increasing energy density as a means to reduce eating rate and food intake would still probably lead to an increased energy intake.

Multiple regression analyses showed that carbohydrate, protein and fibre were inversely associated with eating rate, whereas there was no association with fat. Carbohydrate content of foods can be as high as 80g per 100g of food. These foods have by definition a low water content. This low water content requires mastication to mix enough saliva with the food, to allow for swallowing. In addition, when foods contain complex carbohydrates, protein, or fibre, the texture of these foods is likely to be firm. A firm texture requires sufficient chewing before particles are small or soft enough to be swallowed. Fat was the only macronutrient that was not associated with eating rate, although a negative association was expected based on the observed associations of eating rate and energy density, taking into account that fat is a primary determinant of energy density[31]. The finding that fat was not associated with eating rate suggests that fat may not have an inhibitory effect on eating rate, in contrast to the other macronutrients. This is consistent with the low satiating capacity of fat[32-34], where the inability of fat to "inhibit" eating rate may explain why fat is not very satiating. Fat may provide oral sensations like creaminess and softness[35], enabling a swift passage through the oral cavity, which results in a high eating rate. So the lack of such an inhibitory effect may be caused by the effects that fat has on the texture of foods. It should be mentioned, though, that fat can also provide sensations like crunchiness, as in French fries,[35] which may enhance oral processing and would therefore decrease eating rate. This issue clearly warrants further investigation.

It has been argued that processed foods increase eating rate[7]. Some of our data indeed showed that processed foods had a faster eating rate than the same foods in an unprocessed form (e.g. boiled carrots vs. raw carrots). The relation is more complicated, however, because we also observed that white bread was ingested more slowly than the less processed whole-meal bread. In addition, some of the foods with the lowest eating rates, like caramel toffees and ice cream, were highly processed. This indicates the complexity of eating rate, where multiple food properties are involved. Besides, food properties are often related to each other. Liquid foods, for example, contain a lot of water, so evidently macronutrient content is low. And foods with a firm texture, like meat, usually contain a lot of protein. This stresses the difficulty of pointing to one single food property as a major determinant of eating rate.

There are some limitations to this study. The objective of this study was to investigate eating rate and its association with food intake, considering a large array of foods. It was not feasible for all subjects to test all 45 food items. In the current design, each subject tested seven of the 45 items. As a result, this design required adjustments for between-subject variations in eating rate. Because we could not adjust for this in the analyses, which were performed on food level, not on individual level, we used an individual calibration factor, based on the individual's eating rate of yoghurt and bread. Although this method may be arbitrary, it was nevertheless able to reduce the coefficient of variation of the ingestion time from 0.45 to 0.37. Another limitation is that we calculated a mean eating rate of 50g of a food, not taking into account any changes in eating rate within one session. Previous research has demonstrated that during a meal, eating rate first increases and then decreases[36]. The current design was necessary, however, to study the eating rates of a range of food items in a standardized way. For the same reason, subjects were instructed to consume the foods without pausing between bites. Under normal eating conditions, people may or may not pause between bites. Because we measured eating rate under such laboratory conditions, where the foods were already cut into edible portions, and were not consumed in combination with other foods, the extrapolation of our results to a normal eating situation may be limited.

The present study focused on eating rate of commonly consumed foods. We observed large differences in eating rate between foods and we found positive associations between eating rate and food and energy intake. Due to the nature of this study, we cannot draw any conclusions about causality. Nevertheless, considering the current food supply, with energy dense, low-fibre foods that can be ingested relatively quickly, the consequences of a high eating rate on daily food intake may be considerable. Cross-sectional and experimental data already suggest a link between eating rate and weight status[14,15,37-40], which stresses the potential risk of a high eating rate on body weight gain. In this study, we did not investigate whether subjects adjusted their subsequent food intake to compensate, although an accurate compensatory response is unlikely[41-43]. Since we face an obesity epidemic, it is worthwhile to explore the long-term effects of eating rate on energy balance and which additional food properties, besides macronutrient composition, influence eating rate. Such information could be used in weight maintaining or weight reduction strategies, by creating awareness on the effects of eating rate on food and energy intake. Simultaneously, it poses a challenge for the food industry to develop palatable foods with a low eating rate, to increase their satiating power, without increasing energy density.

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6

Effects of snack consumption for 8 weeks on energy intake and body weight

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Abstract

Consumption of snacks might contribute to the obesity epidemic. It is not clear how the moment of consumption and energy density of snacks can influence the compensatory response to consumption of snacks in the long term. The objective was to investigate the effects of snack consumption for 8 weeks on changes in body weight, emphasizing on moment of consumption and energy density. In total, 16 men and 66 women (mean age 21.9 years (SD 0.3 year), mean body mass index 20.7 kg/m^2 (SD 0.2 kg/m^2)) were randomly assigned to one of four parallel groups, in a 2x2 design: snacks consumed with or between meals and snacks having a low (< 4 kJ/g) or high (> 12 kJ/g) energy density. For 8 weeks, subjects consumed mandatory snacks that provided 25% of energy requirements on each day. Body weight, body composition, physical activity level (PAL), and energy intake were measured in week 1 and week 8. There were no differences in changes in body weight between the four groups. Moment of consumption (*P* = 0.7), energy density (*P* = 0.8) and interaction (*P* = 0.09) did not influence body weight. Similarly, there were no differences in changes in body composition, PAL, and energy intake between the four groups. Body weight after 8 weeks of snack consumption was not affected by moment of consumption and energy density of snacks. This finding suggests that consuming snacks that are high or low in energy density does not necessarily contribute to weight gain. Healthy, nonobese young adults may be able to maintain a normal body weight through an accurate compensation for the consumption of snacks.

Introduction

It is often suggested that the consumption of snacks is an important contributor to the obesity epidemic. This suggestion is supported by some experimental studies that indeed show that consumption of foods between meals does not lead to adequate adjustments in subsequent energy intake[1-6]. These findings suggest that snacks are consumed in addition to meals and therefore lead to a higher daily energy intake. Observational studies, however, do not provide consistent evidence on the associations between snack consumption and body weight status[7-11]. Besides, it seems that the average contribution of snacks to total energy intake was relatively constant (30 – 35%) during the past decades, which suggests that the consumption of snacks is not involved in the increasing prevalence of obesity[12]. The lack of consistent evidence prevents us from making clear recommendations for body weight control.

One of the reasons why snacks may contribute to a positive energy balance is their moment of consumption. By definition, snacks are food items that are consumed outside the context of a main meal. Experimental data indicate that dietary compensation is less accurate when the time span between two eating episodes, such as a snack and a meal, is long (180 min vs. 30 min)[13]. It seems that snacks are only capable of suppressing appetite for 1 or 2h after ingestion, but not substantially thereafter[14,15]. Appetite may therefore no longer be suppressed during a subsequent meal, resulting in a normal meal intake. It is not clear whether dietary compensation becomes more accurate when people get used to consuming snacks.

Another reason why snack consumption may lead to overconsumption is their energy density. Typical snacks, such as cookies, pastries and chips often have a high fat or sugar content and therefore a high energy density (HED). Several studies show that there is no adequate compensation for increases in the energy density of foods. [16-19] It may therefore be argued that the compensatory response to these typical snacks is inadequate because of their HED. If this were the case, then a HED might predispose people to ingest too much energy. And in line with this suggestion, people might be more capable of maintaining their energy balance when the energy density of snacks is low.

The aim of this study was to investigate the effects of snack consumption for 8 weeks on body weight changes in healthy, lean subjects, within a free living situation. We focused on the influences of the moment when snacks were consumed and of the energy density of snacks. We hypothesized that changes in body weight would be lowest when snacks were consumed with a meal, relative to between meals. In addition, we expected the changes in body weight to be the most substantial when snacks with a HED were consumed. In this paper, we use the term ‘snacks’ to refer to the intervention products used in this study, both when they are consumed between meals and with a meal.

Subjects & Methods

Subjects

Men and women aged 18 – 35 years were recruited from Wageningen and surroundings, using flyers and a mailing list. Potential subjects were screened with a questionnaire and an interview to determine whether they met the following inclusion criteria: body mass index 18.5 – 23 kg/m^2; they habitually consumed snacks (>seven times a week); were in good physical and mental health; were weight stable (<1 kg change in body weight during the past 3 months); did not smoke; had not followed an energy-restricted diet during the past 6 months; had no lack of appetite; and were not restrained eaters (men >2.26; women >2.80 on Dutch Eating Behaviour Questionnaire [20]). Normal weight, healthy individuals were selected to study the effects of snack consumption in a situation in which the regulation of food intake is likely to be accurate. Subjects with food allergies or who disliked any of the food products used in the study were excluded. Initially, we included 86 subjects in the study. During the study, four subjects were excluded for lack of compliance (n = 2) or personal reasons (n = 2); therefore the final sample consisted of 82 subjects. The baseline characteristics of subjects are presented in **Table 6.1**. A comparison of the subject characteristics of the four groups did not reveal any differences in age, body mass index, level of physical activity (PAL), energy requirements or dietary restraint score. Subjects provided a written informed consent. The Medical Ethics Committee of Wageningen University approved the study protocol.

Table 6.1 Baseline characteristics of subjects per study group, consuming snacks low or high in energy density and between meals or with a meal.

	Low energy density snacks[1]		**High energy density snacks[1]**	
Characteristics	Between meals (*n* = 21)	With a meal (*n* = 21)	Between meals (*n* = 21)	With a meal (*n* = 19)
Males, *n*	4	6	3	3
Females, *n*	17	15	18	16
Age, *years*	21.5 (1.9)	22.3 (2.6)	22.7 (3.0)	21.1 (1.9)
BMI, *kg/m^2*	21.4 (1.1)	20.4 (1.3)	20.7 (1.5)	20.6 (1.4)
PAL [2]	1.9 (0.2)	1.9 (0.2)	1.9 (0.1)	1.9 (0.2)
BMR, *MJ per day* [3]	6.3 (0.7)	6.2 (0.9)	6.1 (0.6)	5.9 (0.7)
Energy requirement, *MJ per day*	12.0 (2.0)	11.7 (2.5)	11.4 (1.6)	11.3 (1.7)
Dietary restraint score[4]	2.2 (0.5)	1.9 (0.6)	1.9 (0.6)	2.0 (0.6)

[1]Values are means (SD) or *n*; no differences were found between groups for any of the characteristics

[2]Physical activity level (PAL) was assessed with a retrospective questionnaire[21]

[3]Basal metabolic rate (BMR) was assessed with an equation based on body weight and sex[21]

[4]Assessed with the Dutch Eating Behaviour Questionnaire[20]

Design

This study used 2x2 conditions with energy density and moment of consumption as factors. For energy density, we used two levels: a HED level and a low energy density (LED) level. Similarly, we had two moments of consumption: with a meal or between meals. Consuming a snack at least 90 min before or after a meal was considered as between meals. Subjects were randomly assigned to one of four groups. To ensure an equal distribution of men, they were allocated to one of the groups by a randomized complete block design. For 8 consecutive weeks, subjects consumed mandatory snacks daily. They visited the laboratory twice a week to collect the snacks and to measure body weight. In week 1 and in week 8, additional measurements were taken on daily energy intake, body composition, and PAL. Pre-study power calculations showed that 20 subjects were needed in each group to obtain a significant difference of 1.5 kg ($P<0.05$) in body weight change, with an 80% power. In an experiment in which mandatory snacks of 3.0 MJ per day were consumed, people gained an average of 0.25 kg per week. [2] We therefore considered a difference of 1.5 kg in body weight change during a period of 8 weeks as relevant. *Post hoc* power calculations revealed that this study had a power of more than 95% to detect a difference of 1 kg in body weight change. This study is registered in Current Controlled Trials as ISRCTN11886432.

Snacks

The snacks used in this study are all commercially available. In each group, snacks provided 25% of energy requirements. This requirement was based on each subject's basal metabolic rate and PAL[21]. For logistical reasons, three groups were formed on the basis of individual energy requirements (<9; 9 – 11; and >11 MJ per day).Within each energy density level, the same snacks as those consumed with a meal had to be consumed between meals. We therefore selected products that were suitable for consumption at both times. To prevent boredom, different snacks were supplied on a 7-day rotating menu. Products in the LED group had a density of <4 kJ/g and a total weight of 729g (SD 49g) for the group with an energy requirement of <9 MJ per day, 846g (SD 69g) for the group with an energy requirement of 9 – 11 MJ per day, and 1004g (SD 71g) for the group with an energy requirement of >11 MJ per day, averaged over the 7 days. On each day, a fruit, a vegetable and a dairy product were offered. Products within the HED group had a density of >12 kJ/g and a total weight of 130g (SD 10g) for the group with an energy requirement of <9 MJ per day, 151g (SD 11g) for the group with an energy requirement of 9 – 11 MJ per day, and 171g (SD 9g) for the group with an energy requirement of >11 MJ per day, averaged over the 7 days. On each day, we offered a cereal product, a sweet and a savoury snack. After the study, subjects anonymously filled out an evaluation questionnaire on the true intake of the mandatory snacks, to allow an estimate of compliance.

Measurements

Body weight

During the study, body weight was measured twice a week to the nearest 0.1 kg, to examine the changes in body weight over time. A digital calibrated scale (Seca Delta Model 707, Hamburg, Germany) was used. Subjects were weighed after breakfast, wearing light clothing, on days they visited the laboratory to collect the snacks.

Body Composition

Body composition was measured using a Bodpod (Life Measurement, Inc, Concord, CA, USA) to investigate any changes in fat mass and fat-free mass. The Bodpod (within-subject reliability of ca. 2%) measures body density using Air Displacement Plethysmography[22]. On the basis of body density, we calculated fat mass and fat-free mass using the Siri formula. Measurements were taken in the morning, with subjects wearing a swimsuit. Consumption was allowed until 2 hours before the measurement. To standardize measurements, each subject was measured at the same time in weeks 1 and 8.

Physical activity

During weeks 1 and 8, the PAL of the subjects was measured to investigate whether they would change their PAL to compensate for the extra energy intake. Subjects had to report their activity in a diary for seven consecutive days, indicating the activities they had participated in and for how long (hours)[21]. During the same period, subjects wore a pedometer (Yamax Digiwalker SW-200, Tokyo, Japan) and reported their daily step count.

Energy intake

Before the start of the study (week 0), subjects had to report their 24 h food intake in a diary on two random weekdays, to estimate their habitual daily energy intake.

In week 1 and week 8, we observed the food intakes to detect any changes in energy intake due to the study. In both weeks, subjects consumed their breakfast, lunch and dinner in the laboratory for 2 days. For the two bread-based meals, subjects received foods similar to those they had said they consumed habitually. For the warm meal, one main course was provided, with additional vegetables and a dessert. Subjects were provided with preweighed portions, which were offered in twice the amount they normally consumed to ensure unrestricted consumption. Leftovers of the meals were weighed to the nearest 1.0 g. Consumption of any food or drink between meals was reported in a food diary. Energy and macronutrient intakes were calculated using the Dutch Food Composition table[23].

Data analyses

Analyses were performed using SAS version 9.1.2 (SAS Institute Inc. 2004, Cary, NC, USA). Variables are presented as means (SD), unless stated otherwise. For PAL, we first calculated a mean daily level on the basis of the reported 7 days for both week 1 and week 8. Similarly, we calculated a mean habitual daily energy intake on the basis of the reported intake on 2 days (week 0) and a mean daily energy intake on the basis of the observed intakes on 2 days in week 1 and week 8. Missing values in body weight measurements during the study were replaced by the mean value (kg) of the preceding and the following body weight measure of the individual.

Changes in body weight, fat mass and fat-free mass, as well as those of energy intake, and PAL after 8 weeks, were compared within each group by means of a paired t-test. These same variables were compared between the four groups, using an ANOVA (analysis of variance), in which energy density and moment of consumption and their interaction term were treated as fixed factors. To control for baseline measurements and gender, we added these to the model as covariates. Tukey's test was used for *post hoc* analyses. Similarly, we investigated the differences in energy intake between week 0 (habitual intake) and week 1 within each group and between the four groups.

We performed a repeated-measures ANOVA to analyse the changes in body weight during the study period. Within this analysis, moment of consumption, energy density level, and their interaction term were treated as between-subject factors and time as a within-subject factor. Baseline body weight and gender were added to the model as covariates. P-values < 0.05 were considered as significant.

Results

The response rate to the evaluation questionnaire was 76%. Overall compliance seemed to be good, with all mandatory snacks reported to be consumed on 93% of the days. Lowest compliance was found in the HED group consuming snacks between meals, in which all snacks were reported to be consumed on 89% of the days.

Body weight and composition

Figure 6.1 presents data on body weight, assessed with the Bodpod, in week 1 and week 8. In LED groups, body weight increased from 64.6 kg (SD 6.6 kg) to 65.0 kg (SD 6.3 kg) in the between-meals group, and from 63.5 kg (SD 9.1 kg) to 63.6 kg (SD 9.5 kg) in the with-a-meal group. In HED groups, body weight increased from 62.2 kg (SD 6.8 kg) to 62.3 kg (SD 6.7 kg) in the between-meals group, and from 60.3 kg (SD 6.6 kg) to 60.9 kg (SD 7.0 kg) in the with-a-meal

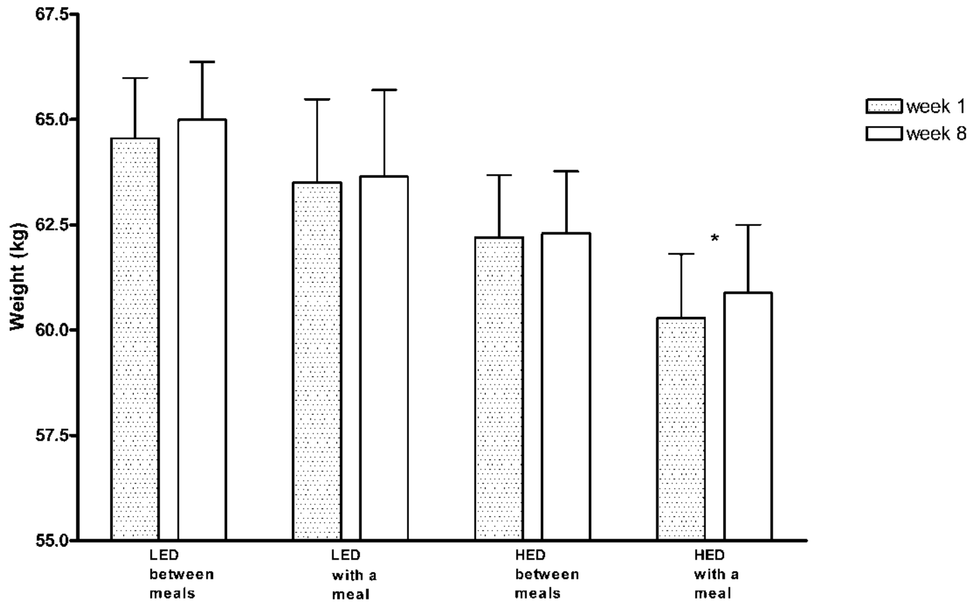

Figure 6.1 *Mean (s.e.m.) body weight (kg) of the four study groups in week 1 and week 8. Snacks were consumed for 8 weeks and were low (LED) or high (HED) in energy density and were consumed between meals or with a meal. * Difference between week 1 and week 8, P = 0.004. Changes in body weight did not differ between the four groups.*

group, which was the only significant increase in body weight throughout the study (*P*=0.004). Changes in body weight were, however, not significantly different between the four groups, which indicates that neither moment of consumption, nor energy density, or their interaction had any influence on changes in body weight.

Changes in body weight during the study are shown in **Figure 6.2**. Changes over time differed between LED and HED groups, with a time x energy density interaction, *P*=0.02. Body weight in LED groups increased slightly during the last weeks of the study, whereas body weight in HED groups was more stable. Differences, however, were minimal, as can be observed in Figure 6.2. There was no significant interaction between time x moment of consumption.

The percentage of body fat in LED groups increased from 23.2% (SD 6.6%) to 24.0% (SD 6.7%) (*P*=0.007) in the between-meals group, whereas it increased from 20.9% (SD 7.3%) to 21.7% (SD 7.3%) (*P*=0.01) in the with-a-meal group. There were no significant changes in the percentage of body fat in the groups consuming HED snacks. Changes in body fat were not significantly different between the four groups; neither moment of consumption nor energy density influenced the percentage of body fat.

Energy intake

The habitual daily energy intake as assessed by the food diaries (week 0), and the energy intake during the study (week 1 and week 8) are presented in **Figure 6.3**. Within each group, the observed total energy intakes (including mandatory snacks) in week 1 and week 8 were significantly higher than the reported total energy intake in week 0 (all *P*'s <0.01), except for the LED, with-a-meal group (*P*=0.07 in week 1 and *P*=0.08 in week 8). Within each group, there were no differences in total energy intake between week 1 and week 8. Between the four groups, there were no differences in change in total energy intake; either between week 0 and week 1, or between week 1 and week 8. This indicates that energy intake remained stable throughout the study and that energy intake did not depend on the energy density of snacks or on the moment snacks were consumed.

Energy intakes of snacks (both mandatory and nonmandatory) and main meals were also investigated separately. We found that in week 1, relative to week 0, nonmandatory snack consumption was significantly decreased within each group (all *P*'s <0.03), except for the HED, with-a-meal group (*P*=0.3). The nonmandatory snack intake remained stable in week 8, relative to week 1. Between the four groups, there were no differences in change in nonmandatory snack intake, either between week 0 and week 1, or between week 1 and week 8.

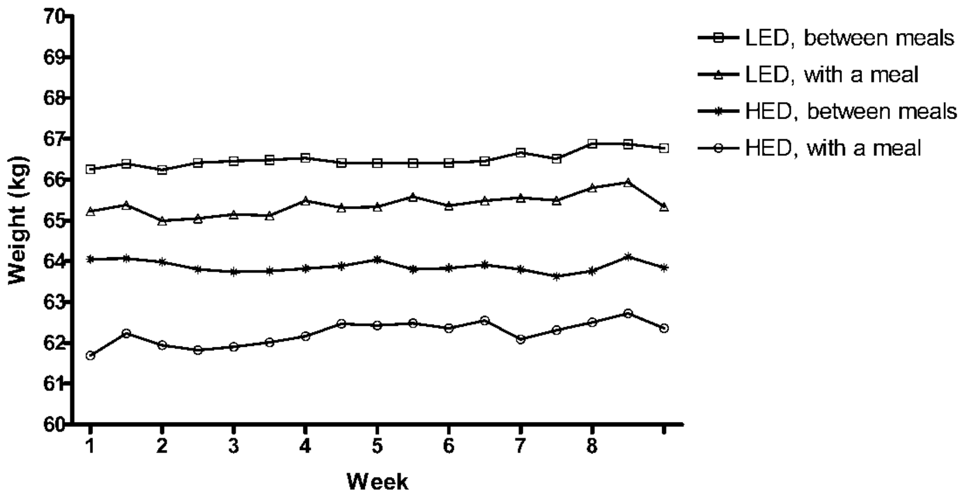

Figure 6.2 *Mean changes in body weight (kg) during 8 weeks of snack consumption. Body weight was measured twice a week. Snacks were low (LED) or high (HED) in energy density and were consumed between meals or with a meal. A significant time x energy density interaction was observed, P = 0.02, corrected for baseline weight and sex.*

When considering the energy intakes of main meals together, there were no changes in intake between week 0 and week 1 within each group, except for the LED, between-meals group (*P*=0.02). The increase in energy intake in this group was due to a higher energy intake in the second bread-based meal (*P*=0.005). A comparison of changes in energy intake between the four groups in week 0 and week 1 showed a small main effect of moment of consumption (*P*=0.053), where the with-a-meal groups lowered energy intakes from the main meals in week 1, relative to the between-meals groups. These differences originated from breakfast (eating moment *P*=0.04) and the second bread meal (eating moment *P*=0.02, data not shown).

There were no differences in changes in energy intake from main meals between week 1 and week 8, either within or between groups. This indicates that energy intake remained stable throughout the rest of the study. No effects of energy density were found.

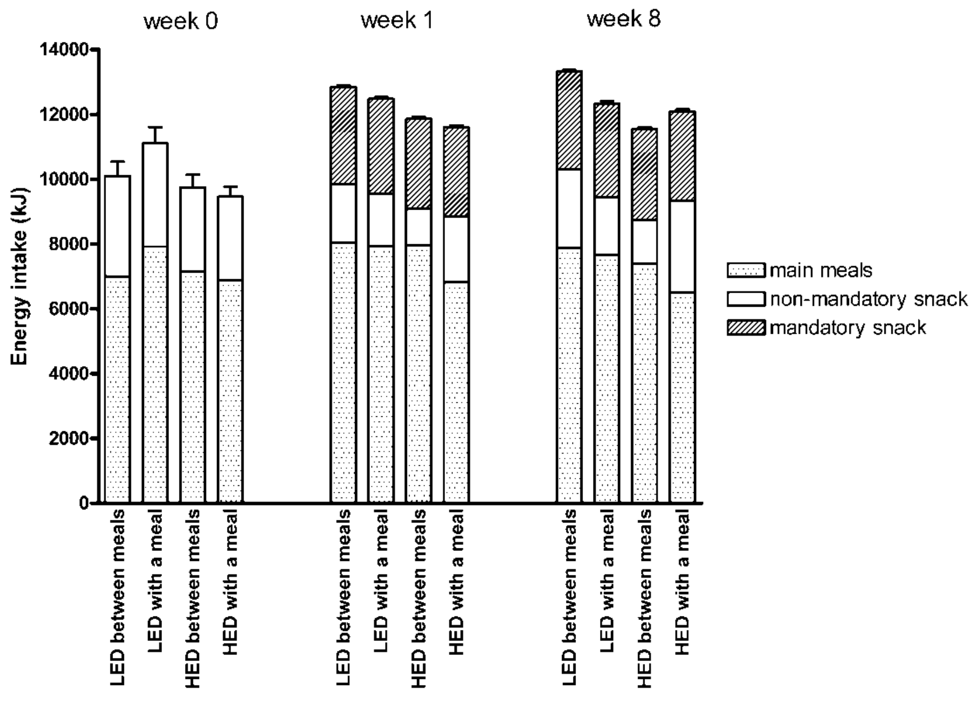

Figure 6.3 *Mean (s.e.m.) daily energy intake (kJ) in week 0 (reported habitual intake), and in week 1 and week 8 (both observed intake), separated into mandatory snacks, nonmandatory snacks, and main meals. Mandatory snacks were consumed for 8 weeks and were low (LED) or high (HED) in energy density and were consumed between meals or with a meal.*

Physical activity

Physical activity level as estimated by the diary, revealed no differences in week 1 and week 8 within each group or between the four groups. This was supported by the daily step counts, in which we did not find any differences between the four groups either. Considering the step counts within each group, however, showed a significant decrease from 11000 steps to 9416 steps (P=0.003) in the LED, between-meals group. Despite these decreased steps in one of the groups, it seemed that, in general, PAL was rather stable throughout the study.

Discussion

This study, which focused on the effects of snack consumption for 8 weeks on changes in body weight, revealed a small but insignificant increase in body weight, which was not affected by the moment snacks were consumed and the energy density of snacks. This suggests that, in this particular population, compensation for the consumption of snacks seemed rather accurate. PAL did not change much throughout the study. Although more research is needed to confirm this, using, for example, doubly labelled water[24], this observation suggests that subjects mainly compensated by adapting their energy intake. This is supported by previous studies showing that total energy expenditure is not affected by meal frequency, which suggests that any effects of snack consumption on body weight are mediated through energy intake and not energy expenditure[7,25,26].

Surprisingly, we found that energy density had no effect on body weight changes. It was previously shown that energy density increased total daily energy intake[27]. This suggests that people should ultimately gain weight on a HED diet. This is indeed supported by two longitudinal studies, in which women on a HED diet gained more weight after 6-8 years, than women on a LED diet[28,29]. Similarly, two long-term weight loss trials showed that weight loss in overweight and obese subjects was highest when the diet was low in energy density[30,31]. Because we provided all groups with the same amounts of energy, the LED groups received more foods in terms of weight and volume than the HED groups. We therefore hypothesized that the LED groups would feel fuller after consuming the snacks and because of that, would reduce their intakes at other eating episodes. We found, however, that body weight was not influenced by energy density. A first explanation for this lack of effect is that our study population consisted of lean, healthy and weight-stable young adults, without any eating disorders, who already managed to stay lean within the current obesogenic environment. They may regulate their energy intake mainly on the basis of internal satiety signals, and may therefore not be susceptible to a HED. This homogeneous population was selected to enable us to link any changes in body weight to the intervention, without any ethical concerns with regard to weight gain in already overweight people, and to control for other confounding variables such as restraint eating. In addition, we could study the physiological effects of snack consumption in a situation in which no disturbances in the regulation of food intake were to be expected. Whether similar results would be found in a population that is prone to gain weight more easily, like overweight subjects, who may rely more on external signals to regulate their food intake, should be investigated. Our results are in accordance with a suggestion of Stubbs and Whybrow, who state that, in the long term, people may compensate more accurately for energy density, because of repeated exposure[32]. A second explanation for our results, in line with this suggestion, is that we used familiar snack products. Because of previous exposure to these products, subjects may have been capable of accurately estimating the energy content. In turn, this may have enabled an adequate compensatory response. A third explanation is that subjects who consumed the LED snacks, consisting of fruits, vegetables, and yoghurts, may still have experienced an appetite for sugary or savoury products and consumed them accordingly, despite the energy they already ingested. It was shown recently that when people think that they consume a healthy snack, they consume 35% more, than when the snack is perceived as unhealthy[33]. A similar phenomenon may have occurred in this study, in which subjects perceived LED snacks as healthy and as a result they were not preoccupied with the energy content of these snacks.

With regard to moment of consumption, we found that subjects regulated their food intake independent of when snacks were consumed. Body weight did not increase when energy intake between meals was 17% (with-a-meal groups) of the total daily energy intake, but neither did it increase when this intake was 37% (between-meals groups). Our findings are in line with a long-term weight loss trial with obese subjects, in which no differences were found in weight loss between subjects consuming three meals a day and subjects consuming three meals and three snacks a day (equicaloric)[11]. The results of the current study are supported by a study of Johnstone *et al.* as well, in which adequate dietary compensation was found for food intake between meals in lean subjects[34]. In literature, two hypotheses with regard to meal frequency can be found[11]. The first one is that multiple eating moments may ameliorate the ability to control energy balance, because of more opportunities to compensate for previous eating episodes. This suggests an adequate physiological energy regulation. This hypothesis is supported by an experiment in which people with a high eating frequency compensated accurately, whereas people with a low eating frequency did not[35]. The second hypothesis is that with multiple eating moments, there may be more opportunities to consume too much energy. This hypothesis is supported by studies in which no adequate compensation was found for energy intake between meals[1,5]. Both hypotheses may be true, but apply to different people. Physiological control may be adequate in some, but clearly not in all people, otherwise we would not face an obesity epidemic. In this study, we could not find clear evidence for either one of these hypotheses. This supports the idea that snack consumption in itself does not necessarily contribute to weight gain, at least in normal weight individuals.

The present study is, to the best of our knowledge, the first study to measure the effects of 8 weeks of snack consumption in a free-living situation, taking into account the moment when snacks are consumed. In this naturalistic setting, we can observe the effects of snack consumption and the compensatory response, without any effects which you might encounter in a laboratory setting. This enhances the external validity. At the same time, this free-living situation results in a limitation. There was no strict control on compliance. An anonymous questionnaire indicated that compliance was rather good (93%); however, we know nothing about subjects (24%) who did not return this questionnaire. A limitation that is common in human behavioural studies, and may apply to the present study as well, is that people become aware of their own behaviour and adjust it consciously. Because in this study, body weight was measured twice a week, it is possible that subjects were aware of the objectives. Although subjects were not allowed to monitor their body weight during the study, any cognitive influences on the compensatory response, in addition to physiological responses, cannot be ruled out. Another point that needs to be addressed is the discrepancy between the reported energy intake in week 0 (~ 9–11 MJ) and the observed energy intake in week 1 and week 8 (~ 11–13 MJ). This higher energy intake during the study was not reflected in changes in body weight. If subjects had truly increased their energy intake during the study, relative to the intake in week 0, they would have gained ~ 2.5 - 4 kg in body weight[36]. However, subjects gained only 0.1 – 0.6 kg. This suggests a measurement error, rather than an actual change in energy intake. Because energy intake in week 0 was self-reported by means of a food diary, it is likely that subjects underreported their intake. We therefore cannot conclude that subjects increased their intake during the study, relative to their energy intake before the study.

Based on our observations, we conclude that a healthy, lean population does not gain weight after consuming snacks for 8 weeks, which suggests an adequate compensation to prevent weight gain, mainly by dietary adjustments. Body weight was not affected by the moment snacks were ingested, which suggests that consuming foods between meals does not necessarily lead to an increase in body weight, at least in a nonobese, healthy population. Energy density of snacks did not influence body weight either. The influences of moment of consumption and energy density should be studied in populations that, behaviourally or genetically, may be prone to gain weight, before any general recommendations on snack consumption can be made for weight management. All subjects in this study regularly consumed snacks. This may have facilitated dietary compensation, in which nonmandatory snacks have been replaced by mandatory products[2]. Therefore, it needs to be investigated to what extent snack consumption influences long-term energy balance in people who do not regularly consume foods between meals.

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7

General discussion

As mentioned in the introduction, the increased prevalence of obesity parallels changes in our food environment, which suggests that the foods we consume are partly responsible for the obesity epidemic. It is clear that certain food characteristics like palatability and macronutrient content affect our food intake. However, the influences of taste, eating rate and energy density are unclear:

There are indications that our diet is becoming increasingly sweet. So far, however, little was known about the actual contribution of taste to the diet. Insight into this contribution was therefore required, in order to investigate possible associations of taste with obesity. In addition, because of the large contribution of highly processed foods to the current diet, it was not clear whether taste, which is supposed to be a nutrient sensor, could serve as signal for nutrients within this diet; nor was it fully clear to what extent a discrepancy between taste and nutrient content would influence food intake.

Eating rate, which seems to be associated with food intake, was so far mainly considered as personality trait, than as food characteristic. But because the eating rate of many of the foods we consume nowadays seems rather high, insight was needed into the actual contribution of eating rate as food characteristic to dietary intake.

Last, energy dense snacks are often blamed for affecting energy balance, but because research findings were inconclusive, this issue warranted further studying.

The general aim of this thesis was to study taste, eating rate, and energy density in relation to dietary intake. In this final chapter, we will first provide a brief overview of the main findings of the research. Next, methodological issues will be discussed, followed by a section on the interpretation of the findings and the research recommendations. Finally, the conclusions and the implications for public health and the food industry will be provided.

Main findings

Taste

In order to investigate the importance of taste to dietary intake, we first studied the contribution of the five taste qualities to the current diet. It was found that the largest part of the daily energy intake originated from sweet foods (34%, chapter 2: taste & eating rate). Neutral foods provided 30% of the daily energy intake and salty/savoury foods provided 25% of the energy intake. Bitter and sour foods provided 6% and 4% of energy intake, respectively. Next, it was investigated whether taste could function as a nutrient sensor in the context of our current diet (chapter 3: taste-nutrient relations). Results showed that sweetness was associated with mono- & disaccharide content (R^2 = 0.45) and that saltiness and savouriness were both associated with sodium content (both: R^2 = 0.33) and protein content (R^2 = 0.27, and R^2 = 0.33, respectively). This suggests that these tastes indeed signal nutrient content of foods, particularly for simple sugars, protein and sodium. The associations were systematically more pronounced in raw and moderately processed foods, than in highly processed foods. This suggests that the ability to sense the nutrient content based on taste may be limited in highly processed foods. In chapter 4 (hidden vs. visible fat), we investigated what the effects on food intake would be, when taste and other sensory properties of fat would be disconnected from the actual fat content. Results showed that food intake was almost 10% lower when fat content was clearly perceivable, than when the fat content was covertly high. These results indicate that when taste and other sensory properties do not accurately reflect the nutrient content of a food, this may lead to higher energy intakes. This applies particularly to highly processed foods.

Eating rate

In providing insight into the contribution of eating rate to the current diet, we demonstrated that a large part of the daily energy intake originated from foods that can be ingested quickly, either in g/min (18%) or in kJ/min (37%). This indicates that the consumption of foods with a high eating rate is relatively high (chapter 2: taste & eating rate). Moreover, food and energy intake increased as the eating rate of foods increased (chapter 5: eating rate & food intake). Because, as we demonstrated in this thesis, the contribution of foods that can be ingested quickly is large and because a high eating rate stimulates food and energy intake, eating rate is a food characteristic that should be considered as a relevant factor that positively affects food intake.

Energy density

Regarding the strong evidence that dietary energy density influences food intake, combined with the suggestion that consuming snacks facilitates weight gain, we wanted to investigate whether it is the energy density of snacks that poses consumers at risk of gaining weight (chapter 6: snack consumption & body weight). Results indicated that snack consumption did not result in weight gain, whether snacks were either high or low in energy density. This suggests that consuming snacks does not necessarily result in weight gain, independent of the energy density of the snacks, at least in normal-weight, healthy young adults. The effects on body weight changes in populations that are more susceptible to gain weight need to be investigated further.

Methodological issues

Careful consideration should be given to the methodological issues, when interpreting the results of the research described in this thesis. In this section, we will discuss a few important methodological issues, in addition to what was already discussed in previous chapters. Some aspects regarding study population and study design will be addressed.

Study population

Representativeness to the general Dutch population

In chapter 2, the objective was to gain insight into the contribution of taste and eating rate to the current diet. As such, the representativeness of the data to the general Dutch population, i.e. the external validity of the study, is a relevant issue. We used data from the Dutch Food Consumption Survey of 2003, which assessed the food intake of 750 young adults, aged 19 – 30 years. The subjects in this survey were considered as representative of the Dutch population in the age group 19 – 30 years, considering age, region and education[1]. Due to underreporting, however, 392 subjects were excluded from the analyses, leaving 202 men and 156 women in the final sample, with a mean age of 25.1 (SD 3.6) y and a mean BMI of 22.5 (SD 2.7) kg/m^2, assuming that length and weight were accurately reported. The mean BMI was somewhat lower compared to the initial sample of 750 subjects. In addition, because in the general Dutch population, 40% of the women and 50% of the men are classified as being overweight[2], the data cannot be considered as representative of the general Dutch population, but only of the normal-weight population.

As mentioned, the Food Consumption Survey was aimed at adults aged 19 – 30 years, and not at older populations. As such, the generalizability of our data to older populations is unclear. There are, however, no indications yet that food intake changes substantially as we grow older, considering the eating rate and taste of the foods that are consumed. This follows for instance from consumption data on beverages, showing that in the age of 22 – 50 y, men drank on average 1.3l and women 1.5l, which was similar as in the age of 50 – 65 y[3]. Therefore, we so far consider our results as generalizable to older Dutch populations as well.

BMI

The experimental studies described in chapter 3 (taste-nutrient relations), 4 (hidden vs. visible fat), 5 (eating rate & food intake) and 6 (snack consumption & body weight) have been performed using young (aged 18 – 35 y), healthy adults, with a BMI in the normal range (18,5 – 25 kg/m^2). We selected these subjects in order to study the effects of the food characteristics in a population that is most likely capable of accurately regulating its food intake. In chapters 4 and 6, we limited the BMI range some more to a maximum of 23 kg/m^2, because in these studies the main interest was the assessment of a compensatory response in food intake in subjects who could accurately regulate their food intake. Although a BMI of, say, 24,5 kg/m^2 is still classified as being normal, subjects with such a BMI may already be starting to develop some overweight. It is therefore questionable whether these subjects would truly be capable of accurately regulating their food intake. To enhance the internal validity, we therefore limited the BMI range in these studies to max 23 kg/m^2. Whether comparable results would be obtained in overweight/obese subjects, requires further investigation.

Restraint eating

Restraint eating is the cognitive awareness of one's food intake and the cognitive, rather than physiological, regulation of this food intake[4]. Dietary restrained eaters have been shown to be more influenced by sensory and dietary information of foods than unrestrained eaters[5,6]. Restraint eating could therefore have affected the results of our studies, where ad libitum food intake was a main outcome measure (chapter 4: hidden vs. visible fat; chapter 5: eating rate & food intake; and chapter 6: snack consumption & body weight), by introducing additional between-subject variation. To eliminate potential effects of restraint eating on food intake, we therefore excluded those subjects that scored high on restraint eating, as assessed with the Dutch Eating Behaviour Questionnaire[7]. By doing so, we sought to select homogeneous study populations regarding restraint eating, which enhanced the internal validity of the studies.

Gender

In all of our experimental studies, both men and women were included. However, we did not have an equal gender-distribution in any of the studies, with women being systematically overrepresented. Considering the design of our studies, however, the consequences of this unequal distribution for our results may be limited: in order to reduce a possible gender-effect, we either reduced the between-subject variation, using reference solutions to measure taste intensity (chapter 3: taste-nutrient relations), or using a calibration to adapt eating rate (chapter 5: eating rate & food intake); we applied a within-subject study design (chapter 4: hidden vs. visible fat); or we ensured an equal number of males in all intervention groups, using a randomized complete block design, and made adjustments for gender afterwards (chapter 6: snack consumption & body weight). Nevertheless, because there are differences in eating behaviour between men and women[8,9], the unequal proportions of men and women may have biased the results, anyway. This would apply particularly to the eating rate measurements (chapter 5), because eating rate may differ between men and women and because the methods to adjust for between-subject variation may not have been sufficient in this study. The internal validity of this study may therefore be impaired.

Study design

Cross-sectional design

The Food Consumption Survey, used in chapter 2 (taste & eating rate), has a cross-sectional design, where food intake was assessed with two 24h dietary recalls. By assessing food intake on two days, rather than on one day, the precision of the habitual food intake was improved[10]. The data therefore provide a good overview of the habitual food intake of the studied population, at the moment of participation. The representativeness of the food consumption data to longer periods or to different seasons is less valid. However, we were mainly interested in food and energy intake according to eating rate and taste of the foods. Since this is the first study investigating this, there are so far no indications that our food intake in terms of eating rate or taste would change throughout the year. Until data become available that suggest otherwise, we consider our findings as generalizable to habitual food intake.

Experimental designs

In the study described in chapter 3 (taste-nutrient relations) we wanted to obtain an estimate of a food's taste intensity, and to associate the taste intensities of the five basic tastes with the nutrient content. In total, 50 food items were used, where all foods were tested by all subjects. In order to reduce the between-subject variation in intensity ratings, we used reference solutions, to create a frame of reference for taste intensity[11]. This should have improved the precision of the taste intensity ratings. Despite the use of the reference solutions, however, there was still considerable variability in taste intensity ratings within a food item, pointing towards the influence of individual differences in the ratings. In order to familiarize the subjects with taste intensity ratings, subjects participated in two training sessions, before the actual test sessions. However, considering the variability we observed in intensity ratings, two training sessions may not have been enough to substantially eliminate the influences of between-subject variability. It may have been better to assess the performance of the subjects on each training session and only to start the study when a sufficient level of performance was obtained (e.g. a deviation of <10% between the intended and perceived intensity ratings), in order to maximally reduce the between-subject variability. In this way, the precision of the intensity ratings would be increased. We expect, however, that, because the error that would be reduced is random, rather than systematic, the consequences for the observed associations between taste intensity ratings and nutrient content would be limited.

The studies described in chapter 4 (hidden vs. visible fat), had a randomized, cross-over design, where all subjects were exposed to all experimental conditions, with the order being randomized. This design made it possible to compare the effects of the experimental conditions within subjects. This has the advantage that many individual variables which may affect food intake are controlled for. As such, the internal validity of the studies was increased.

In the study described in chapter 5 (eating rate & food intake) it was, due to logistical reasons not possible for all subjects to test all 45 food items on eating rate and ad libitum food intake; this would have required that each subject visited the research centre on 45 separate test days. If this design would have been chosen, it would have been very difficult to find sufficient subjects. We therefore chose for a design where subjects were exposed to 7 of the 45 food products. Because the 7 food items were assigned to the subjects on a random basis, this should have resulted in a reduced effect of individual variables on eating rate. Moreover, we also applied a calibration strategy which reduced between-subject variation in eating rate even further. As such, the internal validity was improved and the estimates of the eating rate of the foods and the ad libitum food intake have become more reliable. Nevertheless, due to a limited number of subjects that tested a food item, we cannot exclude the possibility that subject-specific variables still influenced the results; the internal validity may not have been optimal. In future studies, a different design may be preferable, where for example all subjects test a more limited number of food items, or where a more homogeneous study population is selected.

The study described in chapter 6 (snack consumption & body weight), had a randomized parallel design, where subjects were randomly appointed to one of 4 parallel intervention groups. Because there were no differences in subject characteristics between the 4 intervention groups that may have been of influence on the subjects' food intake regulation, we were able to make comparisons between groups, without the internal validity being impaired.

Classification of foods in eating rate and taste categories

In chapter 2 (taste & eating rate), each of the food items that were consumed in the Food Consumption Survey of 2003 were classified according to their eating rate, both in g/min and kJ/min, and according to their taste. The classification according to eating rate may have been somewhat arbitrary: we extrapolated eating rate of 45 food items (chapter 5: eating rate & food intake) to all food items from the Food Consumption Survey. Most food items from the Food Consumption Survey were comparable to one of these 45 food items. However, there were also several food items that did not show much resemblance to any of the 45 food items. For these food items, we had to estimate eating rate based on food characteristics like texture and temperature, which may have had limited precision. In order to counteract this rather rough estimation of eating rate, we limited the eating rate categories to 4. Each category hence contained foods with a rather broad range of eating rates. In this way, we limited the number of items that otherwise may have been misclassified. It should be mentioned that we did not validate the accuracy of the classification. But because we used 4 categories with such large ranges of eating rate, we expect that the accuracy is reasonable. This should be confirmed in a validation study. A consequence is, however, that the precision of the eating rate is hampered. In order to obtain a more precise estimate of the eating rate of foods, it is required to actually measure the eating rate of many more food items than the 45 which we used in this study.

To obtain an estimate of the eating rate in kJ/min, which is determined by eating rate in g/min and the energy density of the food item, we first had to estimate the food's eating rate in g/min. We assumed that the eating rate of the individual food item would be the mean g/min of the eating rate category in which the item was classified. We then multiplied this value in g/min with the energy density of the individual food item. This method seems rather rough and lacking in precision. However, when we correlated the values in kJ/min that we obtained by calculating as proposed here, with the actual measured data on kJ/min of the 45 food items that were used in chapter 5, we found a very high significant correlation between the two measures of kJ/min, with $r = 0.90$. This indicates that the accuracy of the calculated kJ/min is actually rather good.

Similar to the classification in eating rate categories (g/min), we also classified all food items consumed in the Food Consumption Survey into taste categories, according to their predominant taste. Because we demonstrated in chapter 3 (taste-nutrient relations) that a salty and savoury taste were highly correlated ($r = 0.92$), which may suggest that we are not able to make a clear distinction between these tastes, we made one category for both salty tasting and savoury tasting food items. In addition, because there are many food items that do not have a distinct sweet, salty/savoury, bitter or sour taste, we also included a neutral taste category. Based on the data in chapter 3, we assumed that food items with a taste intensity less than 3 on a 15-point scale for all basic tastes, would have a neutral taste. Again, it should be mentioned that we did not validate the classification of the food items into taste categories. However, because there were only a few food items where there was doubt on which predominant taste the items had (for example endive, is this bitter or neutral?), we believe that the classification into taste categories is rather accurate.

Dietary recalls

As mentioned earlier, the food intake in chapter 2 (taste & eating rate) was assessed with two 24h dietary recalls. A dietary recall is a method that relies on self-report. An important drawback of assessing food intake by self-report is the tendency to underreport food intake. This applies particularly to overweight and obese individuals and to certain food groups, like snacks[12]. The level of underreporting in the Food Consumption Survey was estimated to be about 11%, which is comparable to other studies using 24h dietary recalls[13,14]. In order to obtain a more reliable assessment of the habitual food intake, we excluded those individuals that were suspect of underreporting their food intake, using an EI/BMR < 1.35[15]. This lead to a drastic reduction in the number of subjects, where 392 (or 52%) subjects were excluded. Since particularly overweight and obese individuals reported low EI/BMR ratio's, the variance of BMI was reduced. This prevented us from comparing food intake according to taste and eating rate between normal-weight and overweight/obese individuals. This was a setback, because insight into differences in food intake between BMI subgroups would provide relevant information about differences in taste preferences and food choices considering eating rate, which, in turn, may be held responsible for differences in body weight status. However, it should be kept in mind that, so far, there is no perfect method, and therefore no good alternative, to collect food consumption data on such a large scale, without having the problem of underreporting.

Setting

The experimental studies on taste (chapter 3), fat perception (chapter 4) and eating rate (chapter 5) were performed in a laboratory setting. This has the great advantage that environmental conditions are controlled for and that the assessment of the outcome measures, like the ad libitum food intake, is very precise and accurate. As a result of these highly controlled conditions, differences in the outcome measures are attributable to the intervention itself and are not influenced by external variables[16]; the internal validity of these studies is therefore high. Simultaneously, however, subjects may behave differently in a laboratory setting, than in a normal, everyday-life setting. For example, the differences in food intake between the hidden fat and visible fat conditions that we observed in chapter 4 were ca. 10%. But when we would have performed the experiment in a home situation, it is possible that the effects would be less than 10%. The extrapolation of the results to an everyday life situation therefore needs to be done carefully.

The study on snack consumption & body weight (chapter 6) was executed partly in the laboratory (the assessment of the food intake at the start and at the end of the study); the intervention itself, the consumption of the snacks, was done in the subjects' natural environment. In this way, we could study the effects of snack consumption on body weight in normal life. A drawback is that we could not fully control the compliance, i.e. whether subjects really ingested the snacks as they were supposed to. After the study had ended, we did ask for the compliance in an anonymous questionnaire, to get some idea on the degree of compliance, which turned out to be reasonably well.

Food products

In order to study the effects of food characteristics on food intake, one has to select specific foods to be used in the study. The selection of the test foods is critical to obtain a valid answer to the research question. In chapters 3 (taste-nutrient relations) and 5 (eating rate & food intake), we wanted to address the whole diet as we tend to consume it in everyday life. We therefore took great care in selecting about 50 food items, based on how often they are habitually consumed in the Netherlands. Results may have been different when we would have selected other food items. But because we measured taste intensity and eating rate in foods that are commonly consumed in the Netherlands, where more than 80% of the foods we selected were in the top 3 of most often consumed foods within their food group, we believe that the results of the studies do apply to the current Dutch diet.

It is often mentioned that the familiarity of foods, i.e. whether subjects know and regularly consume the foods, influences food intake behaviour. Due to previous exposure, subjects have learned to estimate the satiating capacity of familiar foods[17]. This may affect food intake differently, than when unfamiliar foods are used. In chapter 6 (snack consumption & body weight), we selected familiar snack items, to investigate the effects of energy density of the snacks. As such, subjects had already learned to estimate the satiating capacity and thus the energy content of the snacks. Results may have been different, in case we would have used unfamiliar snacks, where the influence of energy density may have been more pronounced. However, because in real life, people also tend to consume those foods they know, we decided to use familiar foods in this study, for this would make the results more comparable to a normal situation.

Taste

Interpretation

As mentioned in the introduction of this thesis, taste is an important food characteristic that drives our food intake. There are indications that the taste of our diet is changing; consumption data indicate that the intake of caloric sweeteners is increasing[18], which suggests that we tend to consume more and more sweet tasting foods. Assuming that the diet of our ancestors did not contain much sweet tasting foods, except for honey and some fruits, where honey contributed about 2 – 3 % of the energy intake[19], and considering that the intake of added sugars is currently estimated at 15% of total energy intake[20], this suggests a major change in the sweetness of our diet. So far, however, little was known about the contribution of the 5 basic tastes to the current diet. In the study described in chapter 2, we demonstrated that 34% of our energy intake originated from sweet tasting foods. Thirty per cent of our energy intake originated from neutral tasting foods, i.e. foods that lack a predominant basic taste, and 25% originated from salty or savoury foods. So far we are aware of, there has been only one study that investigated the contribution of taste to dietary intake as well. This study showed that 47% of energy intake originated from sweet tasting foods and 39% from salty tasting foods[21]. These percentages differ from ours, but the deviations could be explained by the fact that this latter study did not include a neutral taste category. Nevertheless, both studies agree on a large contribution of sweet tasting foods to our energy intake.

This large contribution of sweet tasting foods may partly be responsible for the high obesity prevalence. This can be seen in non-Western societies that are subject to nutrition transition, where the original diet is changing towards a diet which is high in fats and sugars, which amongst others entail that the diet is becoming increasingly sweet[22,23]. In these societies, a dramatic increase in obesity prevalence is seen[24], which suggests that this increased prevalence is due to the changes in the diet, including augmentations in the sweetness of the diet.

However, it is oversimplified to state that an increased consumption of sweet foods is responsible for the high prevalence of obesity in the Western world. First of all, we cannot compare the data with data from previous decades due to different methodologies. So we cannot investigate changes in the taste of the diet over time. So there are reasons to believe that we consume more and more energy from sweet tasting foods, but it is too early to draw firm conclusions. Second, food consumption data from the Netherlands indicate that the intake of mono- and disaccharides remained relatively stable in the last 15 years, ranging from 22 en% in 1987 to 24 en% in 2003 for young men and ranging from 24 en% in 1987 to 26 en% in 2003 for young women[3,25]. In contrast, the prevalence of overweight individuals in this same period increased from ca. 40% to ca. 50% in men and from ca. 30% to ca. 40% in women[2]. As such, it is not likely that the intake of mono- and disaccharides, which provide a sweet taste, is solely responsible for an increase in obesity prevalence.

Of course, the large intake of sweet tasting foods may also result from foods that contain non-nutritive sweeteners. Although clear data on consumption of non-nutritive sweeteners are lacking, there are indeed indications that the intake of these non-nutritive sweeteners is increasing[26]. This means that in a proportion of the sweet tasting foods we consume, the sweet taste originates from non-nutritive sweeteners, and not from mono- & disaccharides. So, if the consumption of sweet tasting foods is truly augmenting and would indeed contribute to obesity, this should be partly caused by the consumption of foods that are sweet, but lack the nutritional value associated with its sweet taste. This may seem counterintuitive: how is it possible that when you consume foods that do not contain energy or where energy content is reduced, this may result in weight gain?

Non-nutritive sweeteners are often used in food products to reduce the energy content of the food, with the attempt to aid in reducing total energy intake. But so far, there is considerable debate on whether the use of non-nutritive sweeteners is actually helpful in reducing energy intake (for reviews, see[26-28]). Clearly, substituting non-nutritive sweeteners for sugars reduces the energy content of foods and beverages. There are several findings that indicate that this would indeed reduce total energy intake and therefore may help to prevent weight gain[e.g.29,30]. However, some data also suggest that non-nutritive sweeteners actually stimulate appetite, which may induce a compensatory response, resulting in increased energy intakes[28].

How would this work? In non-nutritive sweeteners, taste and nutrient content are incongruent: normally, a sweet taste would predict the delivery of energy. However, non-nutritive sweeteners do not contain energy. The sweet taste is therefore no longer accompanied by the delivery of energy. Some rat studies indicated that when rats were exposed to sweet solutions, which contained energy on only part of the exposures (thus where sweetness was inconsistently paired with energy), this resulted in higher energy intakes and body weight gain, compared to rats that received solutions that were always paired with energy[31, 32]. This suggests that when a sensory signal lacks predictive power, energy regulation is disturbed and tends to result in a positive energy balance. This is corroborated by the results of our study on fat perception (chapter 4: hidden vs. visible fat), where we demonstrated that food intake was higher in the hidden fat condition, where the sensory properties did not accurately predict the nutritious values of the foods. So the degree in which taste and other sensory properties reflect actual nutrient content, may influence food intake in such way that, in case of inappropriate signalling, this tends to result in an increased food intake.

Research recommendations

It is important to consider the previous discussion within the view of the current dietary pattern. As mentioned before, taste, but also other sensory properties like texture and viscosity, acquire their meaning by associating these food-related properties with the metabolic consequences of ingesting the food, and as such with the energetic value of the food. It is important to realize that this taste-nutrient learning is a continuous process: throughout our lives we are constantly exposed to foods. And with each exposure, the meaning of the sensory property gets adjusted, accordingly. So in a situation with a complex interaction between sensory properties and nutrient contents, such as the current food environment, the consequences of inappropriate signalling within single foods on the regulation of food intake may not be that serious. For example, the chances that the sweet taste is consistently paired with a lack of energy are minimal: there are very few food products available that are sweet but do not contain any energy at all. And the likelihood that one would only consume those sweet foods, and no other sweet foods that do contain energy, is small. In addition, if a food is sweetened with non-nutritive sweeteners, the product could still contain energy from protein or fat. As such, sweet taste may still be paired with the positive metabolic consequences, and the nutrient sensing function of the taste will be maintained, due to the continuous nature of taste-nutrient learning.

On the other hand, however, it is not clear what would happen when more and more foods would provide inappropriate signals. In chapter 3 we observed limited associations between taste and nutrient content in highly processed foods, which suggests that in these foods there is an incongruence between taste and nutrient content. Because of the large contribution of highly processed foods to our diet, which is currently estimated at around 60% of our food intake[33], the occurrence of incongruences between taste and nutrient content may augment. Ultimately, the consequences of such incongruences on our food intake may become serious. Clearly, this issue warrants further studying:

The effects of incongruences between sensory properties and nutrient content on actual food intake should be investigated further. It is important to separate the effects of sensory signals that suggest a lower than actual energetic value (as in the case of hidden fats, chapter 4) from the effects of sensory signals that suggest a higher than actual energetic value (as in the case of non-nutritive sweeteners or fat replacers).

The effects of such incongruences should be investigated within the context of everyday life, and not only in laboratory-based conditioning studies. These latter studies may not accurately reflect the complexity of dietary learning in everyday life. One may think of a study, where consumers of fat- or sugar replacers (inconsistent pairing of taste with nutrients) are compared with consumers of original foods (consistent pairing of taste with nutrients), considering their ability to regulate their food intake accurately, based on sensory properties of foods.

Eating rate

Interpretation

An important change in the current diet is an increase in the consumption of foods that can be ingested relatively quickly. This has most clearly been demonstrated by an augmentation in the consumption of energy yielding beverages[34,35]. So it seems that the eating rate of our diet is increasing. There were already some indications that eating rate, as personality trait, is positively associated with food intake and BMI, but eating rate as food characteristic was until now unexplored. In this thesis, we demonstrated that eating rate of foods differed to a great extent between food items, ranging from 4 g/min for rice waffles to more than 630 g/min for diet coke (chapter 5). Even within solid foods, eating rate varied largely between foods, ranging from 4 g/min to ca. 130 g/min. In addition, we demonstrated that eating rate was positively associated with food and energy intake (chapter 5). This finding is in line with previous studies, which demonstrated that eating rate was positively correlated with food intake[36-39]. A recent study even indicated that subjects who claim themselves to be fast eaters gain more body weight in a period of 8 years compared to subjects who are slow eaters[40]. This suggests that the short-term positive effects of eating rate on food intake are uncompensated for and affect body weight on the long term. Although in this study, eating rate was considered as personality trait, these findings may also apply to eating rate as food characteristic.

The positive association between eating rate and food and energy intake and the large differences in eating rate between foods suggest that it depends on the choice of foods, whether eating rate of foods is a potential cause of obesity. In other words, when the intake of foods with a high eating rate is limited, then the contribution of eating rate to obesity would be limited as well. But when a large proportion of the total food intake consists of foods with a high eating rate, this would enlarge the importance of eating rate as a causal factor for obesity. We therefore investigated the contribution of foods with different eating rates to the dietary intake (chapter 2). This study revealed that 18% of our energy intake originated from foods that can be ingested quickly (g/min) and that even 37% of our energy intake originated from foods that can be ingested quickly and simultaneously provide sufficient energy (kJ/min). In itself, these percentages, especially the 18%, may not seem very high. However, in former times, we probably did not consume any energy from foods or beverages with such high eating rates, with the only exception perhaps being some alcoholic beverages and babies drinking breast milk[19]. Previous studies only investigated the consumption of particular groups of foods with a high eating rate, like soft drinks or fast foods[34,35,41]. However, there are many more food items that have a high eating rate, such as desserts and processed meats, which are consumed within an ordinary diet. The additional value of our study (chapter 2: taste & eating rate) is that we investigated total dietary intake, from all food items that are consumed throughout a day. As such, these results give insight in the contribution of eating rate to the whole diet, which turns out to be relatively high. The high consumption of foods with a high eating rate may therefore be partly responsible for the high obesity prevalence.

As mentioned in the introduction, a proposed mechanism why eating rate seems to affect food intake is by the quick passage through the oral cavity, which result in a low orosensory exposure. Due to this low orosensory exposure, relatively few neuronal signals from the oral cavity may be transported to the brain, whereby the brain is not well informed about the foods that are swallowed and enter the digestive tract[42]. This may result in a limited satiety response. There are indeed several studies that demonstrated that food intake increased, when the orosensory exposure to a food was low[43-46], providing support for the proposed mechanism. So it seems that foods that can be ingested quickly have a relatively low satiating value. This clearly follows from studies, where the consumption of foods or drinks with a high ingestion rate lead to lower satiety levels, higher food intakes and even weight gain compared to foods that needed more time to be ingested[29,47-52]. This means that if energy-yielding foods can be ingested quickly, the consumption of such foods may easily contribute to a positive energy balance, because they do not provide adequate levels of satiety. A one-year weight loss trial even demonstrated that weight loss was ca. 2.5 kg greater when soups, which have a low eating rate (kJ/min), were consumed, than when equicaloric snack foods, which have a high eating rate (kJ/min), were consumed[53]. These findings suggest that foods with a low eating rate may be helpful in lowering body weight, possibly through their effects on satiety. But before any conclusions can be drawn, long term intervention studies are needed to confirm this hypothesis.

As stated above, eating rate may exert its influence on food intake through orosensory exposure. Factors that appear to mediate the influences of orosensory exposure on food intake are the duration of the orosensory exposure itself[46,52], the size of the food bolus in the mouth (bite size)[46,54] and chewing on the bite[55,56]. In chapter 5 (eating rate & food intake) we have also demonstrated that energy density, water content and macronutrient composition influence eating rate, probably through affecting the required levels of mastication. For instance, when a food contains much protein, the texture of the food is likely to be firm; a lot of chewing is then required before a bite is small and soft enough to be swallowed. All factors mentioned above can provide leads for the food industry to reformulate existing food products in order to reduce the eating rate and to extend orosensory exposure.

Research recommendations

As mentioned above, food and energy intake seem to be increased when foods with a high eating rate are consumed (chapter 5). In addition, because we tend to ingest about 1/3 of our energy intake from foods with a high eating rate (kJ/min, chapter 2), it is tempting to identify eating rate as one of the factors of our current food environment that are responsible for obesity. However, because of reasons mentioned in the section on methodological issues, we were not able to compare food intake according to eating rate between normal-weight and overweight/obese individuals. We therefore do not know whether differences exist in food choice, where, as we would hypothesize, normal-weight individuals would consume more foods with a low eating rate, relative to overweight/obese individuals. Because some observational studies suggested that obese subjects tend to eat faster than normal weight subjects[57-59], which may indicate eating rate as a personality trait of the obese, but may also reflect the choice for foods with a high eating rate, it is worthwhile to further explore eating rate as food characteristic in relation to obesity:

It should be confirmed whether food items with a high eating rate (kJ/min) indeed provide a low satiety response. In relation to this, the efficacy of reformulating food products to reduce eating rate in order to increase the satiating capacity should be explored.

Long-term effects of eating rate on changes in body weight should be investigated to confirm the recent findings that fast eaters gain more weight than slow eaters[40], whereby eating rate as personality trait should be differentiated from eating rate as food characteristic.

Energy density

Interpretation

A factor in the current food environment that is often held responsible for the obesity epidemic, is the consumption of energy dense snacks. So far, however, evidence was inconsistent. We therefore investigated the effects of consuming snacks, which were either high or low in energy density, on body weight (chapter 6). We demonstrated that there were no changes in weight, following the consumption of snacks, whether the snacks were high or low in energy density. This suggests that snack consumption in itself does not necessarily contribute to weight gain, at least in the studied population. As such, our results support the findings of some long-term studies[60-63] that could not demonstrate that consuming energy dense snacks leads to weight gain. However, there is still quite some evidence suggesting the opposite, i.e. that consuming snacks increases energy intake and is indeed associated with obesity[64-70].

Methodological differences may underlie the conflicting evidence between studies. For example, in observational studies selective underreporting may occur: overweight or obese subjects tend to underreport their snack intake more than normal weight individuals[12,71], which may bias the results towards equal snack intakes in both groups of subjects. An additional reason for the lack of consistent evidence is the selection of the study population, where either overweight or obese subjects[60], lean subjects[61,66,67], or both[62-65,68] were studied, which were either males[64,66-68], females[61] or both[60,62,63,65]. There are indications that subject characteristics, like gender, weight status and dietary restraint status affect the ability to accurately compensate after a high energy intake[8]. So it is likely that these subject characteristics also influence the ability to compensate after snack consumption and thus may influence the outcome of an intervention study. Another explanation for the inconsistent evidence is the duration of the study. Some short-term intervention studies, following a preload – test meal design, did not show any reductions in energy intake in the test meal, following energy-dense preloads[66,67,72], suggesting that consuming energy-dense snacks adds calories to the daily intake, without compensating for it. However, some medium-term intervention studies demonstrated that a partial compensatory response occurred after consumption of energy dense snacks[65,73]. This may suggest that, initially, people are not well equipped to estimate the energy density of a food or meal, and they therefore have to rely on other cues to estimate their energy intake, like stomach distension (volume) or portion size. As such, energy density can have a major effect on actual energy intake, because, by definition, energy dense foods contain many calories in a relatively small amount of food. However, over time, people may learn to estimate the satiating capacity of the food, which may subsequently induce a (partial) compensatory response.

It is important to consider that we are physiologically designed to like energy dense foods: a high energy density in foods provides a satisfying sensation. And through the mechanism of dietary learning, as addressed in the introduction of this thesis, these energy dense foods become preferred[74]. This has recently been demonstrated in an energy-conditioning experiment, where subjects were exposed to either low or high energy versions of a yoghurt drink[75]. After a conditioning period, subjects chose more often for the high energy version of the yoghurt, which indicates that this version was the preferred one. Because of this dietary learning, it is very difficult to resist the ingestion of such energy dense, good tasting foods, especially when we are surrounded by an abundance of these foods. It is likely that the physiological need to maintain energy balance is overwhelmed by the preferences for energy dense foods, particularly in susceptible people. As such, consumption of energy dense foods may not lead to a fully compensatory response, even in the long term, when we theoretically should have learned to estimate the satiating capacity of the foods.

Research recommendations

As is clear from the discussion, evidence regarding the role of consuming energy dense snacks in the aetiology of obesity remains inconclusive. In view of the availability of such foods within our society, with sweet and savoury snacks being sold at school- and sport canteens, in libraries and even in hardware stores[76], and in view of the rising obesity prevalence, it remains important to find clear answers:

The effects of snack consumption in different populations should be investigated, to provide information on whether some individuals are more vulnerable to the effects of energy dense snacks than others. One may think of performing a similar experiment as the one which we performed in chapter 6, but expand it by including different groups of subjects, varying in gender, weight status and restraint eating behaviour (successful and unsuccessful restrained eaters and unrestrained eaters). By combining the latter characteristics, it may be possible to distinguish the influences of a physiological food intake regulation from the influences of a cognitive food intake regulation.

In order to see whether dietary learning occurs based on energy density of snacks, both short- and long term effects of the energy density of snacks should be investigated by assessing the compensatory response at baseline and at the end of a long-term intervention study. This requires the use of unfamiliar food items, with unknown satiating capacities. Such a study will provide insight in the ability to learn to estimate the energetic value of a food over time. Simultaneously, it will provide information about the validity of short-term intervention trials in the study to health related problems as overweight or obesity, which develop in the long term.

Conclusions

In the introduction of this thesis we already mentioned that the increase in the prevalence of obesity coincided with changes in our food environment, which suggests that the foods we consume are at least partly responsible for the obesity epidemic. The research described in this thesis was aimed at specific food characteristics that influence our food intake. We demonstrated that food intake is affected by whether the foods one chooses to consume possess appropriate sensory signals for the nutritious values of the foods. In other words, when taste and other sensory properties of the foods do not accurately reflect the nutritious and energetic aspects of a food, this may lead to inappropriately high food intakes. In addition, we demonstrated that in highly processed foods, the associations between taste and nutrient content were limited, compared to raw or moderately processed foods. This suggests an inappropriate signalling in these highly processed foods; consuming such highly processed foods may therefore contribute to inappropriate food intakes. We also demonstrated that eating rate of foods is a relevant food characteristic in the struggle against obesity: we provided evidence that a high eating rate stimulates food and energy intake and we demonstrated that a large part of the daily energy intake originates from foods which can be ingested quickly, especially compared to the diet in former times. Last, we could not find clear evidence on the role of consuming energy dense snacks in weight gain: body weight was not affected by snack consumption, whether snacks were high or low in energy density. More research is required, however, in more susceptible populations.

General implications

Public health

Based on the findings in this thesis, some public health recommendations for weight management can be made. The Netherlands Nutrition Centre already provides some clear recommendations on how to lose weight effectively. One of these recommendations is to limit the intake of sugar, fat and alcohol. Our findings indicate that the taste and other sensory properties of foods are not always predictive of the nutrients that are present in the food, particularly in highly processed foods. It may therefore be hard for consumers to estimate their sugar and fat intake and to follow the recommendation to limit this intake. It is important that consumers who want to lose weight, become aware of the finding that they cannot always rely on the sensory properties of a food to estimate the food's nutrient content. They should therefore be advised to check the nutrition information presented on the food packages and to compare this between different products within the same food category. In this way, consumers can make informed choices.

Another recommendation of the Netherlands Nutrition Centre is to eat calmly and to pay attention to what one eats. In this way, consumers become aware of what and how much food they really ingest, which may augment their feelings of satisfaction with a certain amount of food. Our findings on eating rate and food intake, with higher food and energy intakes as eating rate of a food increases, may compliment this recommendation: if consumers would choose for those food products that can only be ingested slowly, this aids in eating calmly. The advantage is that by consuming foods that have a low eating rate, it is due to the nature of the food itself that consumers eat calmly; no additional effort has to be made by the consumers themselves.

Last, it is often advised to limit the intake of energy dense snacks. We, however, could not find evidence that supports this advice. In general, there is such inconclusive evidence regarding the role of snack consumption and energy density in weight management, that it is not possible to draw firm conclusions and make public health recommendations. Nevertheless, most studies suggest either no effect or a positive effect of the consumption of energy dense snacks on energy balance, whereas a protective effect against a positive energy balance has hardly been demonstrated. When these findings are considered in combination with the findings that total dietary energy density contributes to weight gain after several years[77,78], the advice for weight management should nevertheless be to limit the intake of energy dense foods, at least until evidence becomes more conclusive.

Food industry

Our research findings provide clear information for the food industry. As indicated, in highly processed foods, taste and other sensory properties do not always accurately reflect the nutritious values of the foods. Because this may affect food intake in a negative way, this is an important aspect to consider in product development. Taste and other sensory properties should at least reflect the energetic value of the food, and should certainly not reflect a lower than the actual energetic value. In this way, an adequate satiating capacity of the food may be achieved. Consumers can then enjoy their food and become pleasantly satisfied after consumption, without having ingested excessive amounts of energy. Another possible way to accomplish this, is to reformulate existing foods in such a way that the eating rate is reduced, which may lead to an increased orosensory exposure and an increased satiating capacity. The texture of a food may for example be toughened or made more sticky, to increase the level of oral processing. Preferably, such reformulations should be applied to those food items that have a high eating rate in kJ/min, because these are the foods that we believe are the most potent ones in stimulating a positive energy balance.

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Summary

Our food environment has changed in the last few decades, with an increased consumption of highly processed, ready-to-eat foods. In addition, our diet has become increasingly energy dense, more energy is consumed in between meals and the foods we select as snacks has changed. The observed changes in our food environment coincided with the increase in the prevalence of overweight and obese individuals, which suggests that the foods we consume are at least partly responsible for the obesity epidemic. It is clear that food characteristics have a large impact on our food intake, with one of the most striking examples being palatability. Less clear are the influences of taste, eating rate and energy density. The present thesis therefore focused at these three food characteristics and their relation to dietary intake.

Taste

Taste was studied in two respects. First, it appears that our diet is becoming more and more sweet. This change in the taste of our diet may underlie the high prevalence of obesity we face nowadays. So far, however, little was known about the actual contribution of taste to the diet. More insight was therefore required, in order to investigate possible associations of taste with obesity. In chapter 2 we therefore investigated the food intake of young adults in terms of taste, using data from the Dutch Food Consumption Survey of 2003. Foods were first classified according to their predominant taste (either sweet, salty or savoury, sour, bitter or neutral). Then, energy intake from the foods within each taste category was assessed. Results showed that the largest part (34%) of the daily energy intake originated from sweet foods. Neutral foods provided 30% of the daily energy intake and salty/savoury foods provided 25% of the energy intake. Bitter and sour foods provided only 6% and 4% of energy intake, respectively. Clearly, a large part of the energy intake originated from sweet foods. It is in this aspect that the current diet seems to have changed, which may underlie health-related problems, like obesity.

Second, taste was studied considering its function as a nutrient sensor. In our current food environment, where up to 60% of all consumed foods is highly processed, sensory properties, like taste, may not be in accordance anymore with the nutrient content, due to technological processes. It is therefore not clear whether taste could still serve as signal for nutrients. In chapter 3, the taste intensities of the five basic tastes (sweetness, saltiness, savouriness, sourness and bitterness) of 50 commonly consumed foods were assessed. The associations of the taste intensities with the nutrient content were investigated. Results showed that sweetness was associated with the mono- & disaccharide content (R^2 = 0.45) and that saltiness and savouriness were both associated with the sodium content (both: R^2 = 0.33) and the protein content (R^2 = 0.27, and R^2 = 0.33, respectively). This indicates that these tastes indeed signal nutrient content of foods, particularly for simple sugars, protein and sodium. The associations were systematically more pronounced in raw and moderately processed foods, than in highly processed foods. This suggests that the ability to sense the nutrient content based on taste may be limited in highly processed foods. In chapter 4, we investigated to what extent a discrepancy between taste and nutrient content would influence food intake, by examining the effects of fat perception (hidden fats vs. visible fats) on ad libitum energy intake during a meal and at subsequent meals. Results showed that in the presence of visible fats, energy intake was almost 10%

lower than in the presence of hidden fats, suggesting that hidden fats may contribute to overconsumption. These results indicate that when taste and other sensory properties do not accurately reflect the nutrient content of a food, which applies particularly to highly processed foods, this may lead to inappropriately high intakes. This hypothesis should be confirmed, by further studying the effects of (in)appropriate signals on food intake within the context of everyday life.

Eating rate

Eating rate, which seems to be associated with food intake and BMI, was so far mainly considered as a personality trait, rather than as a food characteristic. But because the eating rate of many of the foods we consume nowadays seems rather high, insight was needed into the contribution of eating rate as food characteristic to dietary intake. In chapter 2 we therefore investigated the dietary intake in terms of eating rate, using data from the Dutch Food Consumption Survey of 2003. Foods were classified into one of four eating rate categories in g/min (from low to high eating rates) and kJ/min (from slow to fast calories). Then, the mean energy intake of the foods within each category was assessed. Results demonstrated that foods with low eating rates (g/min) provided 47% of the daily energy intake, whereas foods with high rates provided 18% of the daily energy intake. Foods with slow calories (kJ/min) provided only 10% of daily energy intake, whereas foods with fast calories contributed 37% to daily energy intake. These results indicate that currently, the consumption of foods which can be ingested quickly, particularly foods with fast calories, is high, especially compared to the diet in former times.

In chapter 5 we examined how the eating rate of foods affects food and energy intake. First, the eating rate (g/min) of 45 commonly consumed foods was assessed. This was followed by assessing the ad libitum food intake (g) of each food item, from which energy intake was calculated. We observed large differences in eating rate between foods, ranging from 4.2 (SD 3.7) to 631 (SD 507) g/min. Eating rate was positively associated with food intake (β = 0.55) and energy intake (β = 0.001). This study showed that when foods can be ingested rapidly, food and energy intake is high. People may therefore be at risk of overconsumption, when consuming foods with a high eating rate. Considering the current diet, where many foods can be ingested quickly, eating rate of foods is an important characteristic that should be considered as a factor that positively affects energy balance. Before any conclusions can be drawn about the role of eating rate of foods in the aetiology of obesity, the long-term effects of eating rate on energy balance should be investigated.

Energy density

The consumption of energy dense snacks is often blamed for positively affecting energy balance, but because research findings were inconclusive, this issue warranted further studying. We therefore investigated the effects of snack consumption, varying in energy density, on energy balance, as described in chapter 6. In a parallel intervention study, subjects consumed snacks either low (<4 kJ/g) or high (>12 kJ/g) in energy density, either between meals or during meals, for 8 weeks. Body weight, body composition, physical activity level, and energy intake were measured in week 1 and week 8. There were no differences in changes in body weight between the four intervention groups. Energy density of the snacks or the moment of consumption did not influence body weight. Similarly, there were no differences in changes in body composition, physical activity level, and energy intake between the four groups. These findings suggest that consuming snacks, whether they are high or low in energy density, does not necessarily contribute to weight gain. Healthy, normal-weight young adults may be able to maintain a normal body weight through an accurate compensation for the consumption of snacks. Before any public health recommendations can be made on snack consumption in relation to weight management, it is important to study the effects of snack consumption on body weight changes in populations that are more susceptible to gain weight.

Conclusions

The research described in this thesis was aimed at specific food characteristics that influence our food intake. We demonstrated that food intake is affected by whether foods possess appropriate sensory signals for the nutrient content of the foods. In other words, when taste and other sensory properties of the foods do not accurately reflect the nutritious aspects of a food, this may lead to inappropriately high food intakes. In addition, because we demonstrated that in highly processed foods, the associations between taste and nutrient content were limited, which suggests an inappropriate signalling in these foods, consuming such highly processed foods may therefore contribute to inappropriate food intakes. Eating rate is also an important food characteristic to consider in the aetiology of obesity: we provided evidence that a high eating rate stimulates food and energy intake and we demonstrated that a large part of the daily energy intake originates from foods which can be ingested quickly, especially compared to the diet in former times. Last, we could not find clear evidence on the role of consuming energy dense snacks in weight gain: body weight was not affected by snack consumption, whether snacks were high or low in energy density. More research is required, however, in more susceptible populations.

Implications

Based on the findings in this thesis, some public health recommendations for weight management can be made. The Netherlands Nutrition Centre already provides some clear recommendations on how to lose weight effectively, by limiting the intake of sugar and fat and by eating calmly and paying attention to what one eats. Our findings may be helpful in following the recommendations of the Nutrition Centre to lose weight. For example consumers should be advised to choose for foods that have a low eating rate, which forces them to eat calmly.

Our research findings also provide clear information for the food industry. Because taste and other sensory properties do not always accurately reflect the nutritious values of the foods, which may affect food intake in a negative way, it is important that these properties at least reflect the energetic value of the food, and should certainly not reflect a lower than the actual energetic value. In addition, by reducing the eating rate of foods, particularly of those foods that have a high eating rate in kJ/min, their satiating capacity may be increased. In this way, consumers can enjoy their food and become pleasantly satisfied after consumption, without having ingested excessive amounts of energy.

Samenvatting

In de afgelopen decennia is ons voedingspatroon veranderd, waarbij de consumptie van bewerkte producten is toegenomen. Daarnaast is ons voedsel energie dichter geworden en eten we andere en meer producten tussen de maaltijden door. Deze veranderingen in ons voedingspatroon lopen parallel aan de toename van het aantal mensen met overgewicht of obesitas. Dit suggereert dat de veranderingen in ons voedsel (gedeeltelijk) verantwoordelijk zijn voor de hoge prevalentie van overgewicht en obesitas. Het is al duidelijk dat bepaalde eigenschappen van voedsel een grote invloed hebben op onze voedingsinname. Zo is het bijvoorbeeld duidelijk dat hoe lekker we het voedsel vinden bepaalt of en hoeveel we van dat voedsel eten. Van andere voedsel-gerelateerde eigenschappen, zoals de smaak, eetsnelheid en energiedichtheid, is het minder duidelijk of en hoe deze eigenschappen een invloed hebben op onze voedingsinname. In dit proefschrift hebben we daarom zowel smaak, eetsnelheid en energiedichtheid en hun invloed op voedingsinname onderzocht.

Smaak

Smaak hebben we op twee manieren bekeken. Ten eerste hebben we de bijdrage van de vijf basissmaken (zoet, zout, hartig, zuur en bitter) aan ons voedingspatroon in kaart gebracht (hoofdstuk 2). Dit hebben we gedaan, omdat er aanwijzingen zijn dat veranderingen in de smaak van onze voeding één van de oorzaken kunnen zijn voor de ontwikkeling van overgewicht. Voor dit onderzoek hebben we data gebruikt van de Nederlandse Voedsel Consumptie Peiling uit 2003; alle producten die zijn gegeten, zijn ingedeeld in één van vijf smaakcategorieën: zoet, zout & hartig, zuur, bitter of neutraal. Vervolgens hebben we de energie inname per smaakcategorie vastgesteld. De resultaten lieten zien dat het grootste gedeelte (34%) van de dagelijkse energie inname afkomstig was uit zoete producten. Producten met een neutrale smaak leverden 30% van de dagelijkse energie inname en 25% van de energie inname was afkomstig van zoute & hartige producten. Bittere en zure producten leverden slechts 6% en 4%. Uit deze studie komt duidelijk naar voren dat een groot deel van onze energie inname komt uit zoete producten. Om te kunnen concluderen of deze veranderingen ook daadwerkelijk een oorzaak zijn van de hoge prevalentie van overgewicht en obesitas, is het echter noodzakelijk om dergelijke voedselconsumptie data te vergelijken tussen populaties met verschillende gewichtsklassen (normaal gewicht vs. obesitas).

Ten tweede hebben we smaak onderzocht in zijn functie als nutriënt sensor: er wordt algemeen verondersteld dat de smaak van een voedingsmiddel een signaal is voor de nutriënten die er in het voedingsmiddel aanwezig zijn. Een duidelijk voorbeeld hiervan is de zoete smaak, wat typerend kan zijn voor de hoeveelheid suiker in een product. In ons huidige voedingspatroon is echter ca. 60% van de voedingsmiddelen sterk bewerkt. Mogelijk zijn door technologische processen de smaak en andere sensorische eigenschappen niet meer in overeenstemming met de nutriënt-samenstelling. Daarom is het niet duidelijk of smaak nog steeds kan functioneren als nutriënt sensor. In hoofdstuk 3 hebben we daarom de smaak intensiteit van de 5 basissmaken in 50 voedingsmiddelen vastgesteld en deze gerelateerd aan de nutriëntsamenstelling van de producten. De resultaten lieten zien dat een zoete smaak was geassocieerd met het mono- & disaccharide (suikers) gehalte (R^2 = 0.45) en dat een zoute en hartige smaak waren geassocieerd met zowel het natriumgehalte (voor beide: $R^2 = 0.33$) als het eiwitgehalte ($R^2 = 0.27$ voor zoute smaak en $R^2 = 0.33$ voor de hartige smaak). Deze resultaten suggereren dat de zoete, zoute en hartige smaak respectievelijk functioneren als nutriënt sensor voor de nutriënten mono- & disacchariden, natrium en eiwit. De zure en bittere smaak waren niet geassocieerd met een van de nutriënten, wat aangeeft dat deze smaken niet functioneren als nutriënt sensor. Een opvallende bevinding in deze studie was dat in alle gevallen de relaties tussen smaak en nutriënt sterker waren in onbewerkte producten dan in sterk bewerkte producten. Dit suggereert dat wij minder goed in staat zijn om op basis van de smaak de nutriëntsamenstelling van sterk bewerkte producten in te schatten.

In hoofdstuk 4 hebben we onderzocht in hoeverre een afwijking tussen smaak en andere sensorische eigenschappen en nutriënten een effect heeft op de voedingsinname. Hiervoor hebben we de effecten van verborgen vetten in een maaltijd op de energie-inname van deze maaltijd en van latere maaltijden vergeleken met de effecten van zichtbare vetten. Het bleek dat duidelijk waarneembare vetten resulteerden in een bijna 10% lagere energie-inname, vergeleken met verborgen vetten. Dit suggereert dat verborgen vetten bij kunnen dragen aan overconsumptie.

De resultaten van hoofdstuk 3 en 4 samen laten zien dat wanneer smaak en andere sensorische eigenschappen van voedsel niet in overeenstemming zijn met de nutriëntsamenstelling van het voedsel, dit in een experimentele setting kan leiden tot een te hoge voedingsinname. Dit lijkt voornamelijk het geval te zijn in sterk bewerkte producten (hoofdstuk 3). Deze hypothese moet bevestigd worden in vervolgonderzoek, waarbij de effecten van signalen die wel of niet in overeenstemming zijn met de nutriëntsamenstelling onderzocht moeten worden op de voedingsinname in het dagelijks leven.

Eetsnelheid

Er zijn aanwijzingen dat eetsnelheid geassocieerd is met voedingsinname en BMI; tot nu toe is eetsnelheid echter voornamelijk bestudeerd als een eigenschap van een persoon en niet zozeer als een eigenschap van een voedingsmiddel. Omdat veel producten uit onze huidige voeding snel te eten lijken te zijn, en dus een hoge eetsnelheid hebben, was er behoefte aan meer inzicht in de bijdrage van eetsnelheid aan de huidige voedingsinname. We hebben daarvoor wederom data gebruikt van de Nederlandse Voedsel Consumptie Peiling uit 2003 (hoofdstuk 2). Als eerste zijn alle producten die gegeten zijn, ingedeeld in vier categorieën op basis van hun eetsnelheid, zowel in gram/min (lopend van een lage tot een hoge eetsnelheid) als in kJ/min (lopend van langzame tot snelle calorieën). Vervolgens hebben we de energie-inname per eetsnelheidcategorie vastgesteld. De resultaten lieten zien dat producten met een lage eetsnelheid (g/min) 47% van de dagelijkse energie-inname leverden en producten met een hoge eetsnelheid 18%. Producten met langzame calorieën (kJ/min) leverden slechts 10% van de dagelijkse energie-inname, terwijl producten met snelle calorieën 37% van de dagelijkse energie-inname leverden. Deze resultaten tonen aan dat de inname van producten met snelle calorieën relatief hoog is, vooral in vergelijking met de voedingsinname van onze voorouders.

In hoofdstuk 5 hebben we vervolgens onderzocht hoe de eetsnelheid van voedingsmiddelen de voedings- en energie-inname beïnvloedt. Allereerst hebben we de eetsnelheid (g/min) van 45 veel gegeten voedingsmiddelen bepaald. Vervolgens is de ad libitum voedingsinname van deze producten gemeten, waaruit de energie-inname is berekend. Er zijn grote verschillen in eetsnelheid waargenomen tussen producten, lopend van 4.2 (SD 3.7) g/min voor rijst wafels tot 631 (SD 507) g/min voor cola light. Eetsnelheid was positief geassocieerd met voedingsinname (β = 0.55) en energie-inname (β = 0.001). Deze studie suggereert dus dat hoe sneller een voedingsmiddel gegeten kan worden, des te hoger de voedings- en energie-inname is. Men loopt dus het risico op overconsumptie wanneer men producten consumeert met een hoge eetsnelheid. Gezien onze huidige voeding, waarbij er relatief veel ´snelle´ voedingsmiddelen geconsumeerd worden, lijkt de eetsnelheid dus een belangrijke eigenschap te zijn die bij kan dragen aan een positieve energiebalans. Voordat er echter duidelijke conclusies getrokken kunnen worden over de rol van eetsnelheid in de ontwikkeling van obesitas, is het noodzakelijk om de lange termijn effecten van eetsnelheid op de energiebalans te bestuderen.

Energiedichtheid

De consumptie van snacks die veel energie bevatten, wordt vaak als oorzaak gezien van een positieve energiebalans. Maar omdat de bevindingen tot nu toe niet consistent zijn, was er vervolg onderzoek nodig. In hoofdstuk 6 hebben we daarom de effecten van snack consumptie, variërend in energiedichtheid, op de energiebalans onderzocht. Deelnemers consumeerden gedurende 8 weken snacks die ofwel laag (<4 kJ/g) ofwel hoog (>12 kJ/g) in energiedichtheid waren, ofwel als tussendoortje ofwel tijdens een maaltijd. In week 1 en week 8 is het lichaamsgewicht, lichaamssamenstelling, lichamelijke activiteit en energie inname vast gesteld. Er zijn geen verschillen waargenomen in veranderingen in lichaamsgewicht tussen de vier interventie groepen. Zowel de energiedichtheid als het moment waarop de snacks werden geconsumeerd hadden geen invloed op het lichaamsgewicht. Bovendien zijn er geen verschillen waargenomen in veranderingen van lichaamssamenstelling, lichamelijke activiteit en energie inname tussen de vier interventie groepen. Deze resultaten suggereren dat snack consumptie, of het nu snacks zijn met een hoge of een lage energiedichtheid, niet bijdraagt aan de ontwikkeling van overgewicht. Gezonde jongvolwassenen lijken dus in staat om een normaal lichaamsgewicht te handhaven door nauwkeurig te compenseren voor de consumptie van snacks, in ieder geval op relatief korte termijn. Voordat er echter duidelijke aanbevelingen gemaakt kunnen worden op het gebied van snack consumptie, is het noodzakelijk om de effecten van snack consumptie op lichaamsgewicht ook te onderzoeken in populaties die minder goed in staat zijn om het lichaamsgewicht te handhaven.

Conclusies

Het onderzoek beschreven in dit proefschrift was gericht op het bestuderen van eigenschappen van voedingsmiddelen, die onze voedingsinname zouden beïnvloeden. We hebben aangetoond dat de voedingsinname wordt beïnvloed door de mate waarin de sensorische eigenschappen van een voedingsmiddel overeenkomen met de nutriëntensamenstelling van het voedingsmiddel. Met andere woorden, wanneer de smaak en andere sensorische eigenschappen van voedsel niet overeenkomen met de (macro)nutriënten die er in het voedsel zitten, kan dit leiden tot een te hoge voedingsinname. Daarnaast hebben we aangetoond dat in sterk bewerkte producten de associatie tussen smaak en nutriënten beperkt is, in vergelijking met onbewerkte en matig bewerkte producten. Dit suggereert dat we minder goed in staat zijn om de nutriëntensamenstelling in te schatten van sterk bewerkte producten. De consumptie van sterk bewerkte producten kan dus mogelijk leiden tot een te hoge voedingsinname.

Verder hebben we in dit proefschrift laten zien dat de eetsnelheid van een voedingsmiddel een eigenschap is die wellicht een rol speelt in de ontwikkeling van overgewicht en obesitas: we hebben laten zien dat een hoge eetsnelheid leidt tot een hoge voedingsinname. Bovendien hebben we laten zien dat in onze huidige voeding er relatief veel voedingsmiddelen met een hoge eetsnelheid geconsumeerd worden, vooral wanneer we het vergelijken met vroegere eetpatronen.

Als laatste hebben we geen bewijs gevonden voor de hypothese dat het consumeren van energiedichte snacks bijdraagt aan een toename van het lichaamsgewicht: veranderingen in lichaamsgewicht werden niet beïnvloed door snack consumptie, of de energiedichtheid van de snacks nu hoog of laag was. Het is echter belangrijk om verder onderzoek te doen in populaties die minder goed in staat zijn om hun lichaamsgewicht te handhaven.

Implicaties

Op basis van de resultaten van dit proefschrift kunnen enkele aanbevelingen gemaakt worden op het gebied van gewichtsmanagement. Het Voedingscentrum geeft al duidelijke richtlijnen hoe men effectief kan afvallen, onder andere door rustig en met aandacht te eten en door het beperken van suiker en vet in de voeding. Het kan wellicht makkelijker worden om deze aanbevelingen te volgen, door onze onderzoeksresultaten in de aanbevelingen te betrekken. Zo kunnen consumenten bijvoorbeeld geadviseerd worden om te kiezen voor die producten die langzaam gegeten kunnen worden; dit dwingt de consument om rustig te eten.

De resultaten kunnen ook van toepassing zijn op de levensmiddelenindustrie. We hebben laten zien dat smaak en andere sensorische eigenschappen niet altijd in overeenstemming zijn met de nutriëntensamenstelling van producten. Omdat dit een ongunstig effect kan hebben op de voedingsinname, is het belangrijk dat de sensorische eigenschappen in ieder geval bij benadering in overeenstemming zijn met de nutriëntensamenstelling. Daarnaast kan de eetsnelheid van producten met een hoge eetsnelheid (kJ/min) gereduceerd worden, waardoor de verzadigingswaarde toeneemt. Hierdoor kunnen consumenten genieten van de producten en aangenaam verzadigd zijn na consumptie, zonder dat ze (te) grote hoeveelheden energie tot zich hebben genomen.

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About the author

Curriculum Vitae

Mirre Viskaal – van Dongen was born on December 29, 1981 in Waalwijk, the Netherlands. In the year 2000 she passed secondary school (gymnasium) at Dr. Mollercollege in Waalwijk, and in September that same year she started her studies at Wageningen University, where she was enrolled in both the Bachelor program and the Master program of Human Nutrition. She graduated with honours (cum laude) in September 2005. Mirre's first Master thesis was focused on experiences with an orthomolecular therapy of parents from ADHD-patients (a qualitative study), performed at the Division of Communication Sciences, Wageningen University. For her second Master thesis, Mirre performed a case-control study to investigate associations between macronutrient and vitamins B intake and pre-eclampsia, at Erasmus MC in Rotterdam. Mirre performed her internship at UMC St. Radboud in Nijmegen, where she developed a methodology to estimate the nutritional status of children suffering from renal insufficiency. In June 2006 Mirre started with her PhD project, which was funded by the Netherlands Nutrition Centre, the Hague. Her research focused on food characteristics and their influence on food intake. During this PhD project, Mirre joined the educational program of the Graduate School VLAG, she was involved in teaching and supervising master students, and she attended several courses and (international) conferences. Additionally, Mirre was a member of the PhD tour committee, which organized a two-week tour to research institutes and universities in the USA, and a member of the daily board of the committee of temporary scientific staff within the division of Human Nutrition. During her time as a PhD fellow, Mirre fulfilled several tasks, besides her own research: she developed a business case for a computer-tailored feedback program, entitled "Gezondheidscoach", which was aimed at helping people to live a healthy life, providing personal advice. In addition, she developed a research protocol entitled "Oral and Gastric contributions to satiety" in cooperation with Nestle, Switzerland and she edited a book, entitled "Mindless eating: why we eat more than we think", written by Prof. Brian Wansink, from Cornell University, USA, to make this book more applicable for Dutch readers.

List of Publications

Papers in peer-reviewed journals

Taste-nutrient relations in commonly consumed foods. Mirre Viskaal – van Dongen, Marjolein C. van den Berg, Nicole Vink, Frans J. Kok, Cees de Graaf. Accepted for publication in British Journal of Nutrition DOI:10.1017/S0007114511005277

Our food intake described in terms of taste and eating rate. Mirre Viskaal – van Dongen, Frans J. Kok, Cees de Graaf. Submitted for publication

Eating rate of commonly consumed foods promotes food and energy intake. Mirre Viskaal – van Dongen, Frans J. Kok, Cees de Graaf. Appetite 2011;56(1):25-31

Effects of snack consumption for 8 weeks on energy intake and body weight. Mirre Viskaal – van Dongen, Frans J. Kok, Cees de Graaf. International Journal of Obesity 2010;34(2)319-26

Hidden fat facilitates passive overconsumption. Mirre Viskaal – van Dongen, Cees de Graaf, Els Siebelink, Frans J. Kok. Journal of Nutrition 2009;139(2):394-9

Abstracts

Taste-nutrient relations in commonly consumed foods. Mirre Viskaal – van Dongen, Frans J. Kok, Cees de Graaf. Appetite 2011;57(2):567. Annual meeting of British Feeding and Drinking Group (BFDG), March – April 2011, Queen's University, Belfast, UK. Oral presentation

Eating rate in relation to ad libitum food intake of different food products. Mirre Viskaal – van Dongen, Cees de Graaf. In: Abstract book 8th Pangborn Sensory Science Symposium, July 2009, Florence, Italy. Oral presentation

Eating rate in relation to ad libitum food intake of different food products. Mirre Viskaal – van Dongen, Sanne van den Akker, Cees de Graaf. Appetite 2010;55(1):169
Annual meeting of British Feeding and Drinking Group (BFDG), April 2009, Swansea University, Swansea, Wales, UK. Oral presentation

Compensation behaviour after overconsumption: the effects of visible vs. hidden fats. Mirre van Dongen, Cees de Graaf, Frans J. Kok. In: Abstract book British Feeding and Drinking Group (BFDG), annual meeting, April 2007, Newcastle upon Tyne, UK. Oral presentation

Overview of completed training activities

Discipline specific activities

Courses and workshops

Course "Food perception & food preferences"	Graduate School VLAG, Wageningen (NL)	2007 2011
Course "Food intake regulation: nutrient sensing"	Graduate School VLAG, NUTRIM, Maastricht (NL)	2008
Workshop "The influence of sensory and normative cues on human food intake"	Behavioural Science Institute, Radboud University, Nijmegen (NL)	2008

Conferences and meetings

Meetings Werkgroep Voedingsgewoonten	WEVO (NL)	2006 - 2011
Annual meetings of the British Feeding and Drinking Group	BFDG Newcastle upon Tyne (UK) Swansea (UK)	 2007 2009
15th European Congress on Obesity (ECO)	EASO, Budapest (H)	2007
ECO satellite meeting "Nutrition and the brain"	EASO, Budapest (H)	2007
7th and 8th Pangborn Sensory Science Symposium	Elsevier Minneapolis (USA) Florence (It)	 2007 2009
Wageningen Nutritional Sciences Forum	Wageningen University, Arnhem (NL)	2009
Symposium "Sodium, potassium and cardiovascular diseases"	Wageningen University, Unilever, Wageningen (NL)	2010
Symposium "Sensory perception and food intake regulation"	Wageningen university, TIFN, Wageningen (NL)	2010

General activities		
PhD competence assessment	Wageningen Graduate Schools (NL)	2006
NWO talentday "Creatief denken" and "Netwerken doe je zo"	NWO, Utrecht (NL)	2006
PhD introduction week	Graduate School VLAG, Ermelo (NL)	2006
Course "Tutoren training op maat"	Docenten ondersteuning, Wageningen Universiteit, Wageningen (NL)	2007
Course "Design of animal experiments"	Graduate School WIAS, Wageningen (NL)	2008
Course "Scientific Writing"	Language services, Wageningen University, Wageningen (NL)	2009
Course "Writing and presenting scientific papers"	Wageningen Graduate Schools (NL)	2009
Course "Philosophy and ethics of food science and technology"	Graduate School VLAG, Wageningen (NL)	2009
Master class "Starting with the client: new approaches to effective health promotion"	Graduate School VLAG, Wageningen (NL)	2009
Master class "Public health interventions in real-life settings: the AGORA experience"	Graduate School VLAG, Wageningen	2010
Course "Career Assessment"	Meijer en Meijaard, Wageningen (NL)	2010
Course "Good Clinical Practice"	Ziekenhuis Gelderse Vallei, Ede (NL)	2011
Optional activities		
Preparation of research proposals	Wageningen University (NL)	2006 - 2010
Organizing and participating in PhD study tour to USA	Wageningen University (NL)	2007
Literature groups "Journal Club" and "Oldsmobiles"	Wageningen University (NL)	2006 – 2009
Research presentations	Wageningen University (NL)	2006 – 2011

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