ResearchGate

See discussions, stats, and author profiles for this publication at: https://www.researchgate.net/publication/257047515

Oral processing characteristics of solid meal components, and relations with food composition, sensory attributes & expected-satiation

Article *in* Appetite · October 2012

DOI: 10.1016/j.appet.2012.05.063

CITATIONS
8

READS
361

5 authors, including:

Ciaran G. Forde
Wageningen University & Research
130 PUBLICATIONS **3,052** CITATIONS
SEE PROFILE

Nathalie Martin
Nestlé S.A.
113 PUBLICATIONS **3,896** CITATIONS
SEE PROFILE

Some of the authors of this publication are also working on these related projects:

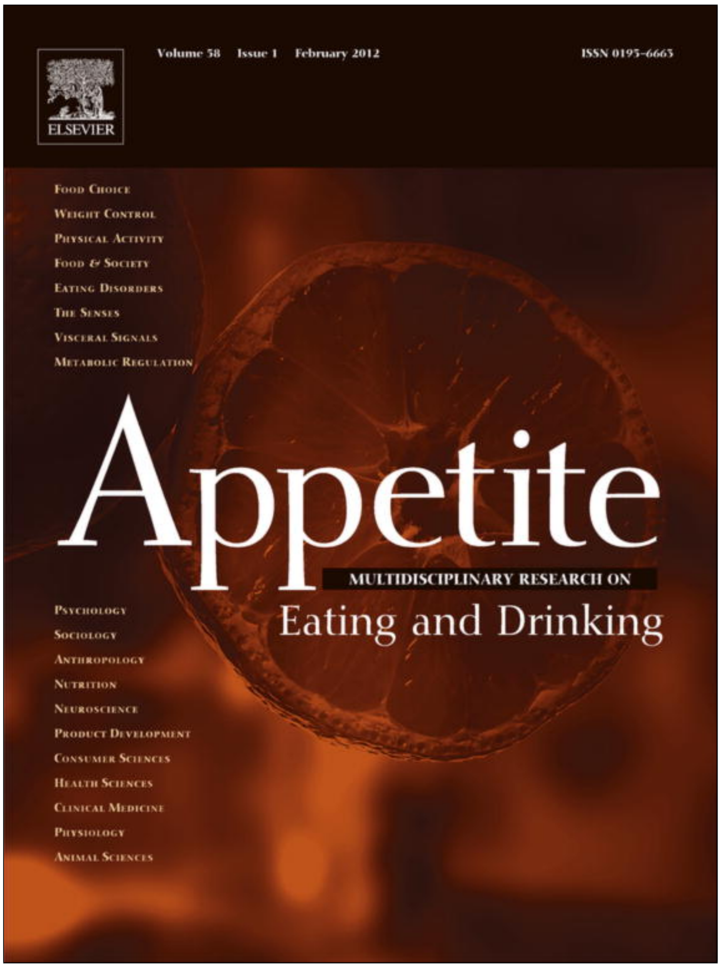
Sensory drivers of portion size selection View project

Methods for Consumer Research, Volume Two: Alternative Approaches and Special Applications View project

All content following this page was uploaded by Ciaran G. Forde on 15 September 2017.

The user has requested enhancement of the downloaded file.

Provided for non-commercial research and education use.
Not for reproduction, distribution or commercial use.



(This is a sample cover image for this issue. The actual cover is not yet available at this time.)

This article appeared in a journal published by Elsevier. The attached copy is furnished to the author for internal non-commercial research and education use, including for instruction at the authors institution and sharing with colleagues.

Other uses, including reproduction and distribution, or selling or licensing copies, or posting to personal, institutional or third party websites are prohibited.

In most cases authors are permitted to post their version of the article (e.g. in Word or Tex form) to their personal website or institutional repository. Authors requiring further information regarding Elsevier's archiving and manuscript policies are encouraged to visit:

http://www.elsevier.com/copyright

Author's personal copy

Appetite 60 (2013) 208–219

Contents lists available at SciVerse ScienceDirect

Appetite

journal homepage: www.elsevier.com/locate/appet

Research report

Oral processing characteristics of solid savoury meal components, and relationship with food composition, sensory attributes and expected satiation [☆]

C.G. Forde [a,*], N. van Kuijk [b], T. Thaler [a], C. de Graaf [b], N. Martin [a]

[a] *Nestle Research Centre, Vers-Chez-Les-Blanc, Switzerland*
[b] *Division of Human Nutrition, Wageningen University, The Netherlands*

ARTICLE INFO

Article history:
Received 12 December 2011
Received in revised form 29 June 2012
Accepted 14 September 2012
Available online 24 September 2012

Keywords:
Oral processing behavior
Bite size
Eating rate
Food oral residence duration
Expected satiation

ABSTRACT

Background: The modern food supply is often dominated by a large variety of energy dense, softly textured foods that can be eaten quickly. Previous studies suggest that particular oral processing characteristics such as large bite size and lack of chewing activity contribute to the low satiating efficiency of these foods. To better design meals that promote greater feelings of satiation, we need an accurate picture of the oral processing characteristics of a range of solid food items that could be used to replace softer textures during a normal hot meal. *Aim*: The primary aim of this study was to establish an accurate picture of the oral processing characteristics of a set of solid savoury meal components. The secondary aim was to determine the associations between oral processing characteristics, food composition, sensory properties, and expected satiation. *Methods*: In a within subjects design, 15 subjects consumed 50 g of 35 different savoury food items over 5 sessions. The 35 foods represented various staples, vegetables and protein rich foods such a meat and fish. Subjects were video-recorded during consumption and measures included observed number of bites, number of chews, number of swallows and derived measures such as chewing rate, eating rate, bite size, and oral exposure time. Subjects rated expected satiation for a standard 200 g portion of each food using a 100 mm and the sensory differences between foods were quantified using descriptive analysis with a trained sensory panel. Statistical analysis focussed on the oral processing characteristics and associations between nutritional, sensory and expected satiation parameters of each food. *Results*: Average number of chews for 50 g of food varied from 27 for mashed potatoes to 488 for tortilla chips. Oral exposure time was highly correlated with the total number of chews, and varied from 27 s for canned tomatoes to 350 s for tortilla chips. Chewing rate was relatively constant with an overall average chewing rate of approximately 1 chew/s. Differences in oral processing were not correlated with any macronutrients specifically. Expected satiation was positively related to protein and the sensory attributes chewiness and saltiness. Foods that consumed in smaller bites, were chewed more and for longer and expected to impart a higher satiation. *Discussion*: This study shows a large and reliable variation in oral exposure time, number of required chews before swallowing and expected satiation across a wide variety of foods. We conclude that bite size and oral-sensory exposure time could contribute to higher satiation within a meal for equal calories.

© 2012 Elsevier Ltd. All rights reserved.

Introduction

The high prevalence of obesity in the industrialized world is partly due to the available food supply. One of the characteristics of our current food supply that contributes to the obesogenic food environment is the large variety of energy dense, palatable and softly textured foods that can be ingested quickly (de Graaf & Kok, 2010; Rolls, 2009, 2010). In a large series of studies, it has been shown that foods that can be ingested quickly (e.g. sugar sweetened beverages) have a low satiating efficiency (for a review see de Graaf, 2011). This is due to oral processing characteristics such as large bite size (Burger, Fisher, & Johnson, 2011; Fisher, Rolls, & Birch, 2003; Spiegel, Kaplan, Tomassini, & Stellar, 1993; Weijzen et al., 2009; Zijlstra, de Wijk, Mars, & de Graaf, 2009), low chewing activity (Li et al., 2011; Smit, Kemsley, Tapp, & Henry, 2011), and a low overall oro-sensory exposure time (Bolhuis, Lakemond, de Wijk, Luning, & de Graaf, 2011; Zijlstra, Mars, de Wijk, Westerterp-Plantenga, & de Graaf, 2008; Zijlstra et al., 2009). By contrast, smaller bite sizes (Weijzen, Zandstra, Alfieri, & de Graaf, 2008; Weijzen et al., 2009; Zijlstra et al., 2009), and more chewing activity (Li et al., 2011; Smit et al., 2011) can lead

---

[☆] *Acknowledgements*: The authors gratefully acknowledge the assistance of D. Gerebtzoff and C. Chilla for their assistance with the observational data coding and validation.

[*] Corresponding author.
E-mail address: ciaran.forde@rdls.nestle.com (C.G. Forde).

0195-6663/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.appet.2012.09.015

Author's personal copy

to longer oro-sensory exposure time (Bolhuis et al., 2011; Zijlstra et al., 2009) and lead to a lower *ad libitum* food intake.

The inter-relationship between a foods composition and its oral processing characteristics have predominantly been studied in model foods, where the texture or oral processing characteristics have been altered on purpose (e.g. Haber et al., 1977; Bolton, Heaton, & Burroughs, 1981; DiMeglio & Mattes, 2000; Leidy, Apolzan, Mattes, & Campbell, 2010; Mourao, Bressan, Campbell, & Mattes, 2007). In most of these studies the texture of foods varied from liquid to semi-solid or solid foods (e.g. Bolton et al., 1981; DiMeglio & Mattes, 2000; Flood-Obbagy & Rolls, 2009; Haber, Heaton, Murphy, & Burroughs, 1977; Hogenkamp, Mars, Stafleu, & de Graaf, 2010; Mourao et al., 2007; Zijlstra et al., 2008). In a recent study, Viskaal – Viskaal-van Dongen, Kok, and de Graaf (2011) showed a positive relation ($R^2 = 0.37$) between the measured eating rate of 50 g of 50 commonly consumed foods and the *ad libitum* intake of these foods. The eating rates in this study varied from less than 10 g/min for rice cakes to up to more than 650 g/min for a diet soft drink. The solid foods in this study were consumed up until an eating rate of about 100 g/min. However, the range of textures used in this and the other studies vary widely, and the experimental foods were not considered as alternatives for each other in an eating occasion. To date, no attention has been given to the eating rate of hot meals components. The hot meal accounts for 30–40% of the daily energy intake in the industrialized world (De Graaf, 2000; Levitsky & Pacanowski, 2011).

Another sensory characteristic that has been implicated in the acceleration of satiation is a higher perceived sensory intensity of food. The effect of sensory intensity on satiation has been shown both for sweet and savoury/salty foods (Bolhuis et al., 2011; Weijzen, Zandstra, Alfieri, & de Graaf, 2008). Higher sensory intensities may lead to lower *ad libitum* food intake through a lower bite size (Bolhuis et al., 2011). One postulated mechanism behind this effect may be that a higher sensory intensity signals a higher macronutrient density. Sweetness and savouriness/saltiness intensities of foods have been shown to relate to the sugar and protein content in an array of 45 commonly consumed foods (Viskaal – Viskaal-van Dongen, Kok, & de Graaf, 2012). Few studies, if any have attempted to establish a formal link between the sensory property of a food and the manner by which it is consumed (i.e. orally processed).

One question that emerges from the results of the previous studies is whether or not the relationship between composition, sensory characteristics, and oral-processing characteristics and satiation also hold in regular commercially available solid foods that may potentially replace each other in a meal. A good understanding of these relationships may help extend the oral exposure of a food in the mouth, increase the interaction with the sensory systems and lead to satiation earlier in an eating event. Alternatively, longer chewing activities could be used to slow the rate of calorie intake within a meal and lead to lower overall calorie consumption. This knowledge could be used to design foods or meals that contribute to moderate energy intakes, while maintaining satiety at adequate levels.

One of the prerequisites of establishing a relationship between oral processing characteristics and other variables is the accurate measurement of variables like chewing activity, swallows, and bite size. Previous studies have used sensors put on the jaws or in the mouth in order to record mouth and swallow movements (Bellisle, Lucas, Amrani, & LeMagnen, 1984; Smit et al., 2011; Stellar & Shrager, 1985). These invasive measures may bias or interfere with the eating behavior itself (Ioakimidis et al., 2011). Recent studies have validated video recordings of chewing using electrical recording of muscle activity with electromyography (Hennequin, Allison, Veyrune, Faye, & Peyron, 2005; Ioakimidis et al., 2011). In the present study we focused on the accurate measurement of oral processing characteristics with the help of a non-invasive behavioral observation techniques that allowed us to code separate bites, chews and swallows in an accurate and valid way, without interfering with the subjects' natural eating behavior.

To measure *ad libitum* satiation for a wide range of savoury food items could be cumbersome and the validity of asking consumers to eat individual meal components to fullness may be questionable. Previous researchers have developed comparisons of foods satiating properties based on consumers' expectations (De Graaf, Stafleu, Staal, & Wijne, 1992; Green, Delargy, Joanes, & Blundell, 1997). In recent years researchers have demonstrated that consumers are capable of discriminating between foods/meals based on how filling they expect them to be, by rating expected satiation or expected satiety (Brunstrom, Shakeshaft, & Scott-Samuel, 2008). Consumers find this task easy to complete, and have been shown to reproducibly discriminate between differences in how filling different foods are expected to be by using picture images of standard food portions (Brunstrom et al., 2008). The current trial measured expected satiation for food items as a proxy measure of participants learned associations between the food and the fullness they would expect from a standard portion.

The primary objective of the current study was an adequate characterization of the oral processing and sensory characteristics of a comprehensive range of savoury tasting solid foods that may be part of a realistic hot meal as consumed in a real life setting. Secondary objectives were to assess inter-relationship among the oral processing characteristics for the different foods, and the assessment of the relationships between oral processing characteristics on the one hand and food composition, sensory attributes and expected satiation on the other hand.

Methods

Overall study design

Thirty-five food items were selected to represent a wide range of savoury meal components including meats, vegetables and several staples. All food items were solids, and were selected to represent differences in macronutrient content, degree of processing, energy density, taste intensity and oral processing times. All food items were commercially available and the full list of food items is highlighted in Table 1. The oral processing behavior for 50 g of the 35 food items was measured using a panel of 15 assessors in a full within subjects design. Subjects were instructed to consume the entire amount of 50 g for each of the food items. On a separate test day, the same 15 member panel completed a measure of expected satiation for a 200 g portion of each food item using a computer based task. A separate trained sensory panel ($n = 11$) profiled the sensory differences between the 35 foods using descriptive sensory analysis.

Subjects – oral processing and expected satiation measures

A power calculation indicated 15 people were necessary to detect differences in eating rate of up to 30% between the 35 foods products, using a within subject variation of 29% with 90% power and $\alpha = 0.05$ (Viskaal-van Dongen et al., 2012). The oral processing panel consisted of a total of five male ($N = 5$, age 29.6 ± 15.3) and ten female ($N = 10$, age 25.1 ± 3.6) volunteers that were recruited from within the Nestle Research Centre. The study was assessed and approved internally having met the ethical criteria required for sensory studies of this nature. Participants were screened to ensure they were within the normal range for BMI of 18–25 kg/m^2, (Males = 23.1 ± 1.9, Females = 20.9 ± 2.2), were not following a calorie restricted diet and not currently pregnant or lactating. High

Author's personal copy

Table 1
Macro-nutrient content and mean sensory intensities for the 35 food items.[a]

Food products	kcal/ 100 g	Protein (g/100 g)	Carbohydrate (g/100 g)	Fat (g/100 g)	Salt (g/100 g)	Fibers (g/100 g)	Water (g/100 g)	Overall flavour	Saltiness	Sweetness	Savouriness	Firmness	Chewiness
Boiled potatoes	62	1.5	14	0.5	0.004	1.6	78	33.4	28.8	14.2	24.1	11.4	22.0
Broccoli (cooked)	27	3.9	0.8	0.3	0.005	2.7	91.4	33.1	10.1	7.7	10.4	21.5	31.7
Broccoli (steamed)	27	3.9	0.8	0.3	0.005	2.7	91.4	38.7	17.5	17.3	20.4	56.0	53.6
Bulgour	339	11	66	1.2	0	10	77.8	18.4	4.3	8.5	3.6	13.2	32.1
Burger (homemade)	213	19	1	15	0.04	0	60	30.2	14.1	15.9	21.8	28.1	63.3
Burger (premade)	209	18	1	15	0.39	0	54.4	67.3	55.8	27.5	55.8	18.8	40.3
Carrots (boiled)	32	0.7	5.2	0.3	0.025	2.8	90.4	47.6	9.7	60.5	7.1	44.1	45.4
Carrots (mashed)	23	0.5	2.7	0.5	0.15	1.8	93	44.7	13.4	57.8	9.6	2.7	9.1
Carrots (raw)	33	0.6	5.5	0.3	0.027	2.7	90	40.5	3.8	53.0	4.5	87.4	66.9
Chicken breast	116	25	1	1.5	0.04	0	60.1	40.6	25.6	11.0	29.1	35.2	67.9
Chicken nuggets	177	16	12	7	0.5	0	54.3	51.7	44.6	24.2	41.0	32.6	54.4
Chicken sliced	100	21	1	1.5	0.8	0.5	64.2	57.8	66.3	10.1	42.2	10.5	26.8
Egg	155	13	1	11	0.15	0	76.2	32.3	14.9	13.6	9.6	14.9	31.9
Fish fingers	188	13	16	8	0.3	0.4	53.8	48.4	38.4	15.2	33.5	16.3	39.5
Fried potatoes	151	2.5	24	5	0.01	3.2	32.7	35.7	28.9	16.7	13.9	34.7	46.9
Garlic bread	318	8	42	12	0.44	2.2	43.1	55.9	42.0	11.2	40.9	45.0	55.9
Hotdog	201	13	5.5	14	0.69	0.5	67	69.1	66.7	20.9	61.6	25.6	43.4
Lasagne	173	10	13	9	0.44	0.4	68.1	61.1	49.2	18.3	42.7	19.8	36.8
Mashed potatoes	89	2	14	2.5	0.075	0.8	84.3	23.0	13.1	12.6	9.1	0.8	4.9
Minced beef	213	19	1	15	0.04	0	60	28.9	19.3	14.7	20.4	27.0	47.7
Mushroom (canned)	18	2.5	0.5	0.5	0.3	2.5	92	47.8	40.6	13.1	32.0	26.0	37.0
Pasta	356	15	67	2.5	0.21	1.4	63.7	15.4	3.6	16.5	3.8	19.8	35.8
Pizza	229	10	22	11	0.5	1.7	59.4	61.8	49.0	23.5	48.2	48.0	55.0
Quiche	246	9	16	16	0.36	1.1	66.8	68.7	65.2	18.8	40.1	29.8	37.6
Rice	343	7	77	0.5	0.01	1	63.4	14.4	4.2	8.7	4.3	19.0	37.4
Salmon canned	164	23.5	0	7.8	0.5	0	70	57.9	53.1	9.2	46.3	16.4	44.9
Salmon smoked	165	25	0.5	7	1.1	0	62.6	87.0	85.7	8.3	75.7	11.1	24.2
Salmon steak	167	23.7	0	8	0.08	0	68.3	66.7	55.3	10.4	46.0	18.0	42.5
Steak	139	26.7	0.7	3.3	0.062	0	70	40.6	25.7	12.0	30.6	52.5	90.9
Steak pieces	139	26.7	0.7	3.3	0.062	0	70	42.1	28.9	10.2	32.1	53.1	86.8
Tofu	145	16	2	8	0.19	0.3	77.6	28.7	10.2	13.5	6.2	17.5	47.2
Tomatoes (canned)	24	1.5	4.5	0.5	0.1	0.7	94.1	54.6	37.8	18.8	36.4	5.5	9.1
Tomatoes (raw)	20	0.7	2.9	0.4	0.002	1.4	95.4	38.1	10.9	14.7	13.9	27.4	29.5
Tortilla chips	482	7	62	22	0.59	4.3	2.6	72.2	64.0	16.3	51.0	53.0	54.0
White fish (cod)	81	19	0.5	1	0.16	0	76	45.0	27.1	6.2	25.8	16.3	41.8

[a] Based on package information and the Dutch Food Composition Table (NEVO-online version 2011/3.0).

Author's personal copy

dietary restraint was also excluded and participants were asked to complete the restraint section of the Dutch Eating Behavior Questionnaire (Van Strien, Frijters, Roosen, Knuiman-Hijl, & Defares, 1985). Participants had no food allergies, intolerances or specific food dislikes, and all were familiar with the 35 foods tested. Participants gave their informed consent before being allowed to participate in data collection. The same subjects completed the oral processing measures and the expected satiation task.

Trained sensory panel

The sensory differences between the 35 food items were characterized using a trained descriptive sensory panel of 11 trained female sensory assessors (aged = 43.8 ± 6.1 y) that had previously been screened for normal sensory acuity and had broad experience across a range of product categories.

Experimental procedure

Oral processing measures

The oral processing behavior measures were taken at lunch time each day and participants were invited to consume a standard 50 g portion of each food item, with 7 food items served each test day, across 5 consecutive test days. Participants received all 35 products and for practical reasons, the same 7 products were served within each test session. The order of sample presentation was randomized within each session to reduce order effects. Subjects were instructed to consume their normal breakfast the morning of the test session and not to eat for the three hours before the lunch-time session. All food items were served in individual sensory booths and subjects had access to 150 ml of water and were encouraged to rinse between foods during the session. Each lunch-time session lasted approximately 45 min. Each test session began with hunger and fullness ratings recorded on 100-mm line scales, and on receiving each food item participants were asked to rate their liking for the food on a 100 mm line scale.

Each individual sensory booth was fitted with a computer equipped with a webcam that was positioned approximately 30 cm from the participant below the monitor. When participants were served the 50 g portion of each food item, they were instructed to eat at their usual rate while being video-recorded. Participants were informed prior to the session that they would be recorded on video, but were unable to see themselves on the video display and were not informed which behaviors were measured since this may have influenced their eating behavior. Several subjects did not consume one or two individual foods items, such that a total of 509 (out of 15 × 35 = 525) video recordings were coded for their oral processing behavior using specialized behavioral observation software (Noldus Information Technology BV, "The Observer XT", The Netherlands). A coding scheme was developed for the Noldus software to record the frequencies of three key point events (bites, chews and swallows) and simultaneously coding the duration and frequency of a state event (total oral exposure time). An example of a coding scheme for approximately ten bites highlighting the oral exposure time, bites, chews and swallows is shown in Fig. 1. This approach enabled accurate oral exposure time measures as only the time spent by the food in mouth was collated to create a final figure. The average bite size was calculated by dividing the total weight of food consumed by the number of bites required to consume it. Relationships between original measures enabled chew rate (chews/s), bite size (g/bite), chews/bite, and eating rate (g/time) to be calculated. Eating rate was calculated by taking the weight of food consumed and dividing it by the total oral exposure time required to consume it. All video coding was completed by a single coder. The coding scheme and performance was validated through standard reliability measures by a second trained coder to achieve an acceptable range (min. 80% of agreement).

Descriptive analyses of the 35 food items

The sensory panel were trained over three days during which time products were tasted and sensory attributes were proposed and defined. Reference standards were used during attribute definition and model taste solutions were prepared based on previously published levels for sweetness, saltiness and savouriness (Viskaal-van Dongen et al., 2012). The panel received some of the 35 food items during training sessions to familiarize them with the frame of reference for the evaluation. For the sensory assessment, each assessor received 10 g of each food item that had been prepared using the same cooking procedure as the oral processing test. All samples were profiled in duplicate by all assessors and the order of presentation was randomized within each test day to reduce first order and carryover effects. Between products assessors were encouraged to cleanse their palates with water and bread during the 3 min break between samples. All data collection was completed using the Fizz program (Fizz, Biosystems, Couternon) for computerized data collection and all sensory intensities were captured on a 100 mm line scale anchored from "not at all" to "extremely" for each of the different sensory attributes rated. The six sensory attributes profiled are defined in Table 2.

Expected satiation

In a separate session, the 15 volunteers from the oral processing measures were invited to perform the expected satiation task, such that differences in eating behaviors could be linked back to differences in expected satiation from the same group. A standard 200 g portion of each of the 35 food items was photographed on a white plate of diameter 255 cm. Camera angle, lighting and position above the plate were standardized to minimise visual differences between each image. The 35 food items were prepared using the same standardized procedure as for the oral processing and sensory measures to ensure consistency across all measures. All data was collected using the data acquisition software Fizz and participant hunger and fullness were rated at the beginning of the session to ensure all participants were in a similar hunger state when making their judgements. Participants were presented with the food item image on screen and asked to rate "how filing would you expect this portion of this food to be?" Participants rated the

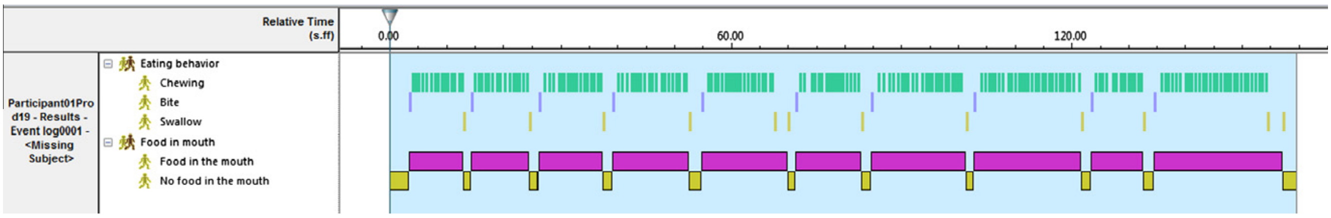


Fig. 1. Illustration of coding scheme for the assessment of number of bites, swallows and chews with the help of video observation. In this study, 15 people consumed 50 g of each of 35 foods, representing savoury solid component of the hot meal.

Author's personal copy

Table 2
Sensory attributes, definitions and scale anchors for the 35 food items profiled.

Sensory attribute	Definition	Anchors
Overall flavour	The overall flavour intensity associated with the taste & smell properties of the food	Low to high
Sweetness	The sweetness of the sample as associated with the sweetness of sucrose	Low to high
Salt	The saltiness of the sample as associated with NaCl	Low to high
Savoury	The savoury intensity of the sample as associated with mono-sodium-glutamate	Low to high
Firmness	The firmness of the sample defined by the force required for the first bite	Low to high
Chewiness	The chewiness associated with the work required to chew the sample before swallowing	Low to high

expected satiation on a 100 mm line scale anchored from ''not full at all'' to ''extremely full''. This procedure was repeated for the 35 food items and image presentation order was randomized across participants. Average expected satiation values were calculated for all 35 food items by averaging across participants.

Data analyses

Oral processing behavior data was collected using a full cross over design. To account for differences between subjects, a Linear Mixed Model was constructed incorporating a random subject effect. This approach accounted for the differences between subjects and with incomplete data sets from one or two subjects. Summary values for each measurement were presented as estimated means based on a Linear Mixed Model taking subjects as a random factor. The reported *F*- and *p*-values denote the *F*-value associated with the fixed product effect and the corresponding significance respectively. A Fisher's Least Significant Difference (LSD) was calculated to indicate the minimum difference required between two products. Spearman's rank correlations between each measure were calculated based on the estimated means to obtain a robust estimate of the relationship between the measures. Spearman's rank correlation coefficient has been used throughout as it is robust to specific deviations from the center. All data analyses were carried out using the software R 2.12.1 while the library ''nlme'' was used to estimate the effects of the Linear Mixed Models.

The sensory data was analyzed using the Fizz software to produce estimated means for correlation against the other measures in the study. The estimated means were calculated for each of the sensory attributes using a General Linear Model with product as a fixed effect, and a random subject effect. Differences between the attributes were assessed by ANOVA and a summary plot of all sensory differences was prepared using Principal Components Analysis (PCA). Each assessor's expected satiation estimate for the 35 foods was also analyzed by a Linear Model and the estimated means, *p*-values and *F*-ratio's for each product were summarized to highlight the differences between products.

Results

Oral processing characteristics

Bites and swallows

Table 3 summarizes the main oral processing characteristics for each of the 35 foods. The average observed number of bites to consume 50 g of a product varied from 5 for raw tomatoes to 33 for tortilla chips, which is a 6-fold difference between the two foods. For most foods, the number of swallows coincided with the number of bites, with a high correlation ($R^2 = 0.94$, $p < 0.001$) between the average number of bites and the average number of swallows across the 35 foods. The average bite size varied reciprocally with number of bites (negative correlation $R^2 = 0.68$, $p < 0.001$), from 1.6 g per bite tortilla chips to about 10 g per bite for tomatoes, such that foods consumed with small bite sizes required a larger number of bites to be processed. Two thirds of the foods had a typical bite size of 5–8 g.

Chews eating rate and oro-sensory exposure time

The average observed number of chews was 155, and varied from 27 for mashed potatoes to 488 for the tortilla chips, resembling an 18-fold difference. Foods consumed with a smaller number of chews were also consumed with fewer bites ($R^2 = 0.69$, $p < 0.001$). For most products the number of chews per bite was between 10 and 20 (Table 3). The mashed products and canned tomatoes had a smaller number of chews (<7 chews/bite), whereas some protein rich products had a higher number of chews (>20 chews/bite). The average eating rate for the 35 food items is summarized in Fig. 2. Eating rate varied from 12 and 101 g/min, and was inversely related to the number of bites ($R^2 = 0.23$, $p < 0.001$), chews ($R^2 = 0.59$, $p < 0.001$) and swallows ($R^2 = 0.35$, $p < 0.001$). Softer foods, like mashed carrots, lasagna, mashed potatoes, and canned tomatoes had the highest eating rates.

Oral exposure time co-varied with the number of bites ($R^2 = 0.74$, $p < 0.001$) and number of chews ($R^2 = 0.98$, $p < 0.001$) such that longer oral exposure times were associated with more bites and chews. The lowest oral sensory exposure times were about 28–30 s for canned tomatoes and mashed potatoes (=0.6 s exposure/g food), whereas tortilla chips was an outlier with 349 s (=7 s exposure/g food). Pieces of steak, raw carrots and fried potatoes had the longest oral exposure times of about 180 s, which is equivalent of 3–4 s for each g of food (Table 3).

In most cases, food processing led to a decrease in oro-sensory exposure time. For example, from raw to mashed carrots, 175 → 53 s/50 g; boiled potatoes → mashed potatoes, 59 → 29 s/50 g; raw tomatoes → canned tomatoes, 47 → 28 s/50 g; steamed broccoli → boiled broccoli, 131 → 79 s/50 g. However, not all food processing led to faster eating times as was seen when homemade burger was compared to premade burger, chicken breast was compared to chicken nuggets and salmon steak compared to canned salmon all of which had approximately equal exposure times.

Chewing rate

Whereas there were 6–18-fold differences between products in terms of the number of chews, number of bites, eating rate and oral sensory exposure times, the differences in chewing rates were smaller between products. Chewing rate was lowest for the mashed potatoes with about 31 chews/min, whereas raw carrots required 86 chews/min. Overall, the chewing rate among the foods was very consistent, with thirty of the 35 products having chewing rates between 55 and 75 chews minute, i.e. around 1 chew/s.

Relation between food composition and oral processing characteristics

Figure 3a–f shows the relationship between macronutrient content, energy density, water content and total number of chews. Water content was only measure that was significantly correlated to the expected satiation ratings and this was found to be negatively related to the number of chews ($R_{sp} = -0.36$). Energy density

Author's personal copy

Table 3
Summary of the oral processing behaviour and expected satiation ratings for 50g of the 35 food items (±Standard Error).

Product of bites	Average no.	Chews (*n*)	Swallows (*n*)	Chew rate (chew/min)	Chews per bite	Bite size (g/bite)	Oral exposure time (s)	Eating rate (g/min)	Expected satiation[a]
Boiled potatoes	8 (0.9)	78 (17.8)	8 (0.9)	56 (4.1)	11 (1.9)	6.8 (0.5)	59 (12.7)	53.3 (4)	67 (5.0)
Broccoli (cooked)	8 (0.9)	116 (17.8)	8 (0.9)	66 (4.1)	16 (1.9)	6.9 (0.5)	79 (12.7)	41.5 (4)	39 (5.0)
Broccoli (steamed)	10 (0.9)	196 (18)	10 (0.9)	68 (4.1)	20 (2)	5.4 (0.5)	131 (12.8)	26.5 (4)	48 (5.0)
Bulgour	11 (0.9)	182 (17.8)	12 (0.9)	68 (4.1)	16 (1.9)	4.8 (0.5)	127 (12.7)	28 (4)	74 (5.0)
Burger (homemade)	7 (0.9)	147 (18.1)	9 (0.9)	68 (4.1)	21 (2)	7.3 (0.5)	105 (13)	32.2 (4.1)	79 (5.0)
Burger (premade)	8 (0.9)	136 (17.8)	9 (0.9)	66 (4.1)	18 (1.9)	6.8 (0.5)	94 (12.7)	35.6 (4)	79 (5.0)
Carrots (boiled)	6 (0.9)	149 (18)	7 (0.9)	75 (4.1)	24 (2)	8.2 (0.5)	92 (12.8)	36 (4)	43 (5.0)
Carrots (mashed)	9 (0.9)	68 (18)	9 (0.9)	50 (4.1)	8 (2)	6.2 (0.5)	53 (12.8)	64.6 (4)	46 (5.0)
Carrots (raw)	9 (0.9)	290 (18)	10 (0.9)	86 (4.1)	32 (2)	5.9 (0.5)	175 (12.8)	19.3 (4)	37 (5.0)
Chicken breast	9 (0.9)	190 (17.8)	11 (0.9)	68 (4.1)	22 (1.9)	6 (0.5)	136 (12.7)	26.6 (4)	64 (5.0)
Chicken nuggets	9 (0.9)	187 (17.8)	11 (0.9)	73 (4.1)	20 (1.9)	5.5 (0.5)	124 (12.7)	27.2 (4)	76 (5.0)
Chicken sliced	10 (0.9)	137 (18.1)	12 (0.9)	57 (4.1)	15 (2)	5.4 (0.5)	95 (13)	33.3 (4.1)	77 (5.0)
Egg	6 (0.9)	85 (18.1)	7 (0.9)	57 (4.1)	17 (2)	9.5 (0.5)	68 (13)	47.7 (4.1)	76 (5.0)
Fish fingers	8 (0.9)	108 (17.8)	8 (0.9)	61 (4.1)	14 (1.9)	6.6 (0.5)	78 (12.7)	42.7 (4)	66 (5.0)
Fried potatoes	18 (0.9)	259 (17.8)	15 (0.9)	73 (4.1)	15 (1.9)	3.4 (0.5)	176 (12.7)	20.3 (4)	79 (5.0)
Garlic bread	8 (0.9)	162 (17.8)	8 (0.9)	66 (4.1)	21 (1.9)	6.9 (0.5)	116 (12.7)	27.9 (4)	70 (5.0)
Hotdog	8 (0.9)	141 (17.8)	8 (0.9)	73 (4.1)	19 (1.9)	6.9 (0.5)	90 (12.7)	36.5 (4)	83 (5.0)
Lasagne	6 (0.9)	63 (17.8)	6 (0.9)	51 (4.1)	11 (1.9)	8.9 (0.5)	48 (12.7)	66.1 (4)	63 (5.0)
Mashed potatoes	8 (0.9)	27 (17.8)	8 (0.9)	31 (4.1)	4 (1.9)	6.7 (0.5)	29 (12.7)	93 (4)	50 (5.0)
Minced beef	13 (0.9)	199 (18.1)	12 (0.9)	70 (4.1)	15 (2)	4.1 (0.5)	138 (13)	24.2 (4.1)	79 (5.0)
Mushroom (canned)	9 (0.9)	138 (18.1)	9 (0.9)	73 (4.1)	16 (2)	6 (0.5)	86 (13)	39.7 (4.1)	43 (5.0)
Pasta	11 (0.9)	184 (17.8)	11 (0.9)	70 (4.1)	17 (1.9)	5 (0.5)	127 (12.7)	27.6 (4)	63 (5.0)
Pizza	8 (0.9)	144 (17.8)	9 (0.9)	65 (4.1)	18 (1.9)	6.4 (0.5)	101 (12.7)	31.8 (4)	66 (5.0)
Quiche	7 (0.9)	100 (17.8)	9 (0.9)	55 (4.1)	15 (1.9)	7.4 (0.5)	79 (12.7)	38.6 (4)	80 (5.0)
Rice	10 (0.9)	132 (17.8)	10 (0.9)	62 (4.1)	13 (1.9)	5.3 (0.5)	93 (12.7)	34.8 (4)	67 (5.0)
Salmon canned	11 (0.9)	177 (18.1)	11 (0.9)	63 (4.1)	16 (2)	4.8 (0.5)	138 (13)	26 (4.1)	62 (5.0)
Salmon smoked	12 (0.9)	127 (18.1)	12 (0.9)	57 (4.1)	12 (2)	4.9 (0.5)	89 (13)	36.7 (4.1)	60(5.0)
Salmon steak	9 (0.9)	102 (18.1)	10 (0.9)	58 (4.1)	11 (2)	5.8 (0.5)	79 (13)	40.6 (4.1)	65 (5.0)
Steak	9 (0.9)	209 (17.8)	10 (0.9)	69 (4.1)	24 (1.9)	6.4 (0.5)	146 (12.7)	26.2 (4)	76 (5.0)
Steak pieces	16 (0.9)	282 (17.8)	16 (0.9)	73 (4.1)	18 (1.9)	3.3 (0.5)	192 (12.7)	18.2 (4)	79 (5.0)
Tofu	7 (0.9)	199 (18.6)	10 (1)	67 (4.1)	31 (2)	7.9 (0.5)	145 (13.3)	27.7 (4.2)	64 (5.0))
Tomatoes (canned)	6 (0.9)	36 (17.8)	6 (0.9)	39 (4.1)	7 (1.9)	9.1 (0.5)	28 (12.7)	101.1 (4)	26 (5.0)
Tomatoes (raw)	5 (0.9)	69 (17.8)	6 (0.9)	62 (4.1)	14 (1.9)	10.2 (0.5)	47 (12.7)	63.2 (4)	33 (5.0)
Tortilla chips	33 (0.9)	488 (18.1)	25 (0.9)	74 (4.1)	15 (2)	1.6 (0.5)	349 (13)	12.4 (4.1)	72 (5.0)
White fish (Cod)	10 (0.9)	115 (18.1)	10 (0.9)	63 (4.1)	12 (2)	5.5 (0.5)	85 (13)	40 (4.1)	55 (5.0)
F value	45.2	38.3	23.0	28.6		22.6	31.5	41.2	11.4
df	34	34	34	34		34	34	34	34
P value	0.0000	0.0000	0.0000	0.0000		0.0000	0.0000	0.0000	0.0000
LSD	2.0	38.1	2.0	5.5		1.0	28.8	8.4	1.2

[a] Rated on a 100 mm VAS scale.

Author's personal copy

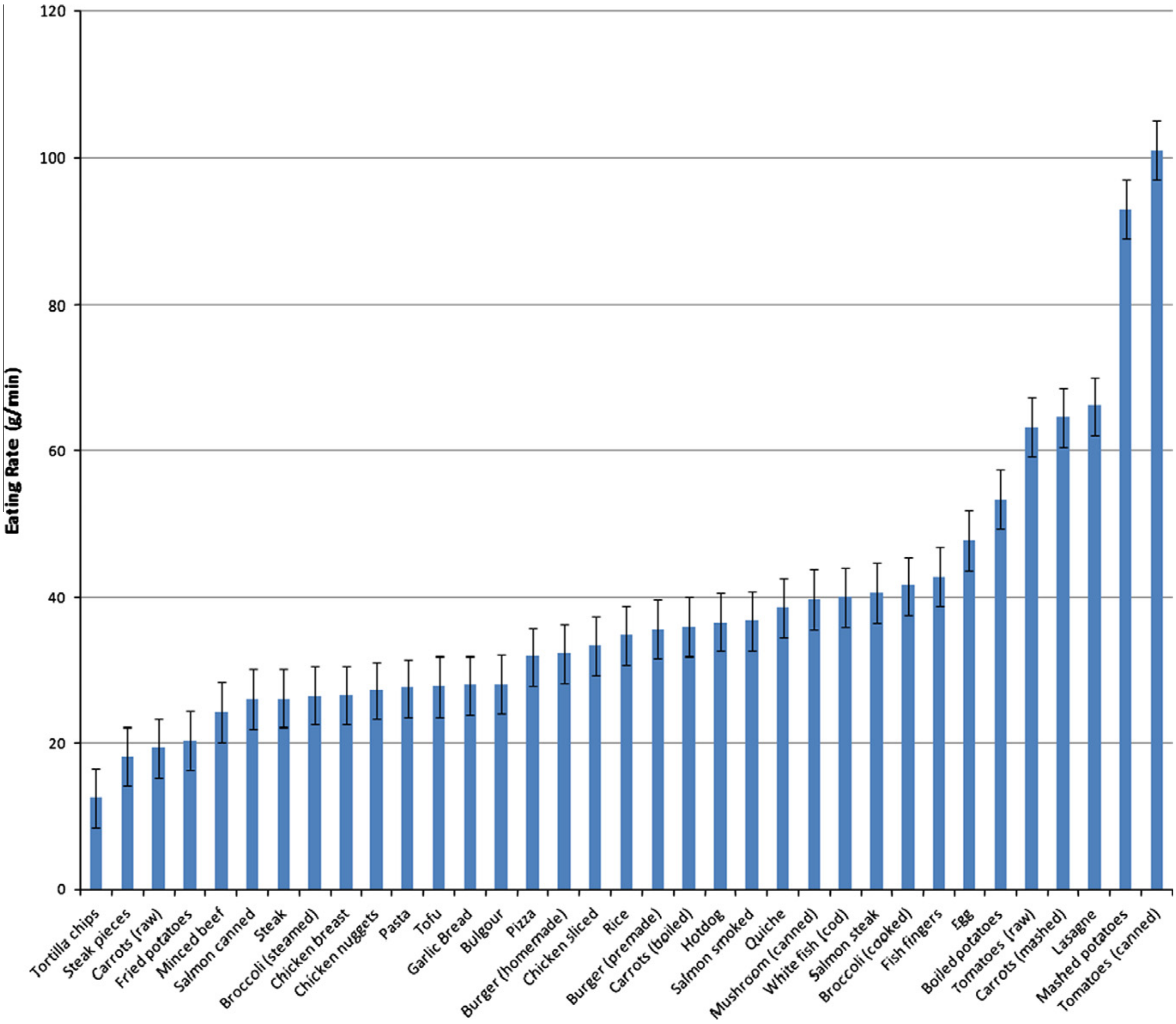


Fig. 2. Mean eating rate (g/min) for the 35 food items (±Standard Error).

($R_{sp} = 0.25$), protein ($R_{sp} = 0.29$), carbohydrate ($R_{sp} = 0.01$), fat ($R_{sp} = 0.11$) and fiber content ($R_{sp} = 0.09$) were not significantly related to the number of chews. There was a positive though non-significant relationship between total protein content and total chews which indicated that foods with higher protein content perhaps had more structure and as such required more chews to process before swallowing. It is interesting to note that for the most part, chew rate was independent of the composition of the foods, such that neither energy density, water content nor macronutrient content significantly influenced the rate at which the different food items were chewed.

Relation between sensory profile and oral processing characteristics

Figure 4 shows a bi-plot summary of the sensory profile of the 35 tasted foods and indicates two main dimensions along which the foods were separated. The first dimension related to differences among products in overall taste/flavor intensity whereas the second dimension related to differences in the texture properties. Saltiness was highly correlated to savouriness ($R^2 = 0.92$, $p < 0.001$) and overall flavor intensity ($R^2 = 0.81$, $p < 0.001$), but not to sweetness ($R^2 = 0.04$, $p < 0.23$). As shown in Table 1, raw, boiled and mashed carrots were the only products with significant levels of sweetness. Premade burger, sliced chicken, quiche, tortilla chips and smoked salmon were the product with the highest flavour intensity (>6.8 on 100 mm scale).

The strongest relationships between the sensory profile and oral processing characteristics were seen between the two texture related attributes (chewiness, firmness), and not with the four taste characteristics (overall flavor intensity, saltiness, savouriness and sweetness). Chewiness was positively related to number of chews ($R^2 = 0.40$, $p < 0.001$), chew rate ($R^2 = 0.52$, $p < 0.001$) and oral exposure time ($R^2 = 0.37$, $p < 0.001$), but negatively related to eating rate ($R^2 = 0.54$, $p < 0.001$). Overall, the variation in each food items taste intensity did not influence the way in which the food was orally processed.

Expected satiation

Figure 5 shows the expected satiation scores in increasing value, from about 2.6 for canned tomatoes to about 8 for hotdogs. Hotdogs, quiches, burgers and steak pieces were among the products expected to confer the most satiation, whereas cooked and mashed vegetables and the fish product were expected to confer

Author's personal copy

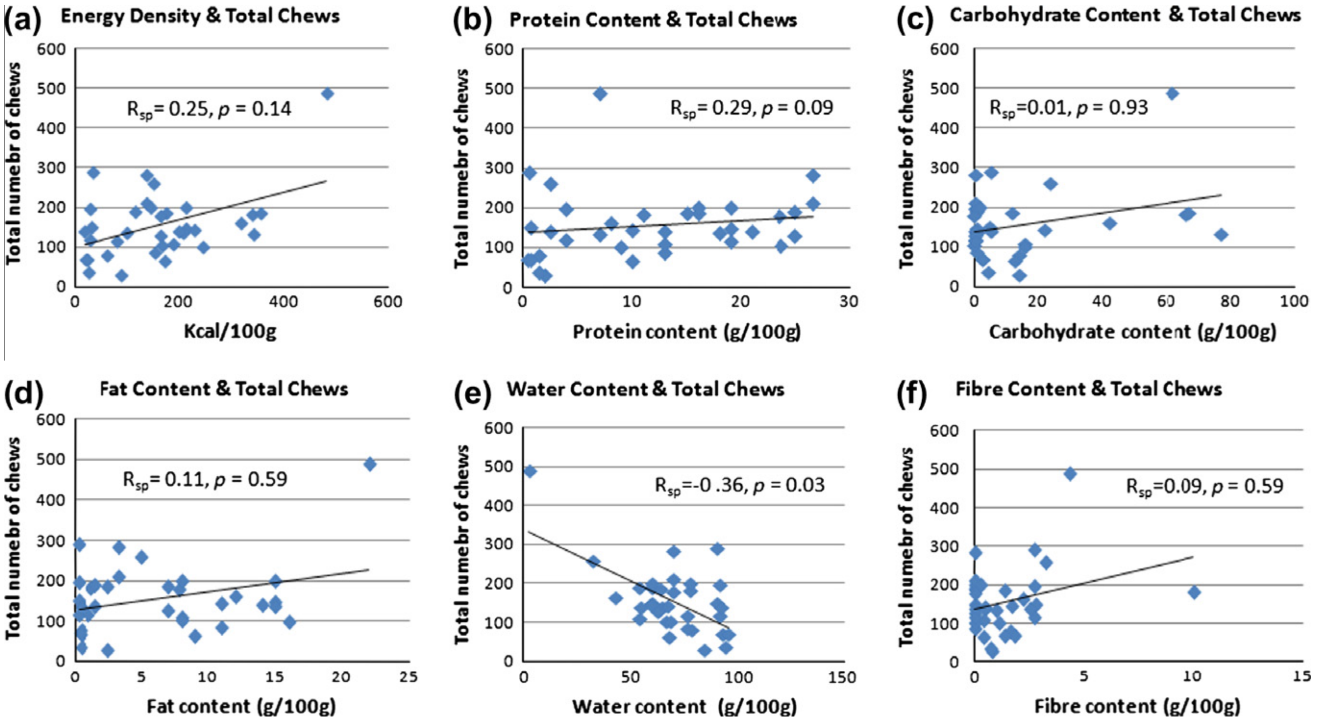


Fig. 3. Correlation between observed total number of chews and (a) energy density, (b) protein, (c) carbohydrate, (d) fat, (e) water content, and (f) fiber content on the one hand (independent variable), for the 35 foods. Spearman's correlations (R_{sp}) are reported for the relationship between nutrient value on the x axis and average number of chews across 15 subjects for each product.

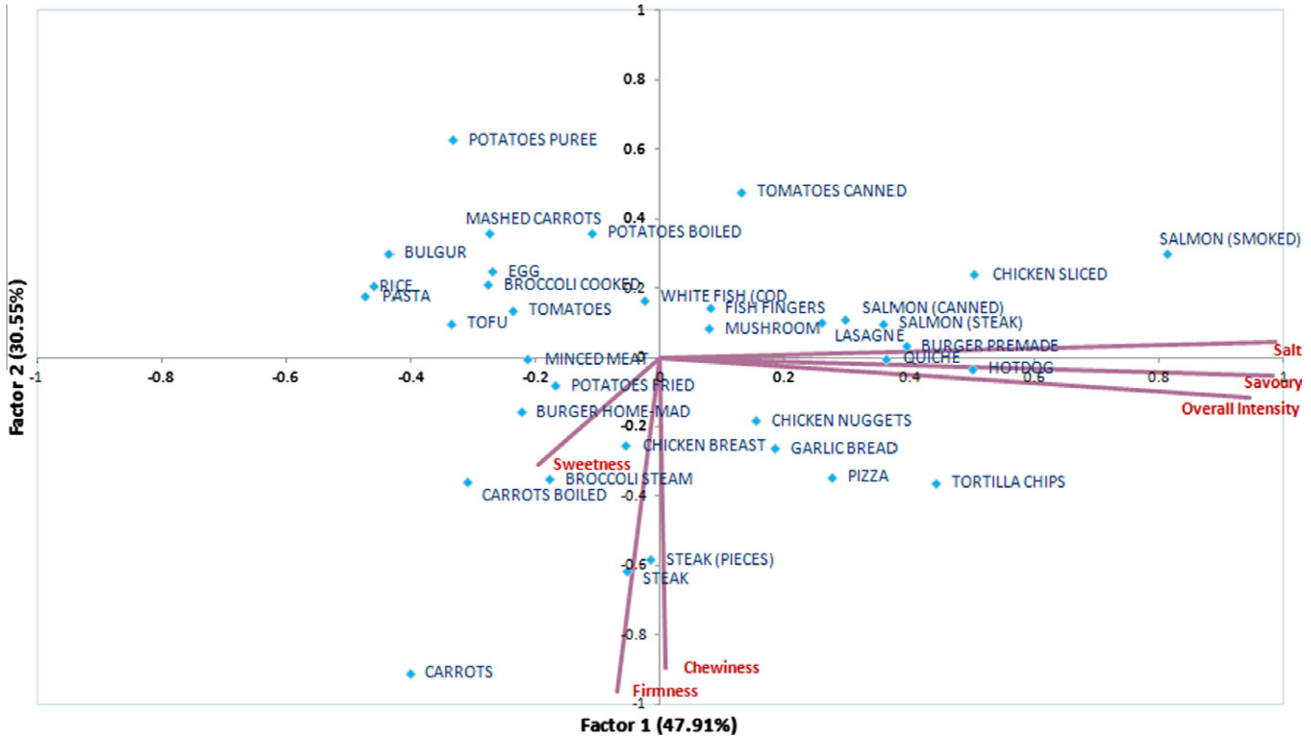


Fig. 4. Principal Components Analysis (PCA) of the mean sensory intensities for the 35 foods items.

relatively poor satiation. It is interesting to note that raw, boiled and mashed carrots had similar scores with respect to expected satiation.

Expected satiation was related positively to energy density ($R^2 = 0.40$, $p < 0.001$), the protein content ($R^2 = 0.33$, $p < 0.001$), and the fat content ($R^2 = 0.38$, $p < 0.001$), but negatively related to the water content ($R^2 = 0.46$, $p < 0.001$). Carbohydrate and fiber content were not significantly correlated to expected satiation scores. With respect to the sensory attributes, there was a significant positive association with saltiness intensity ($R^2 = 0.12$,

Author's personal copy

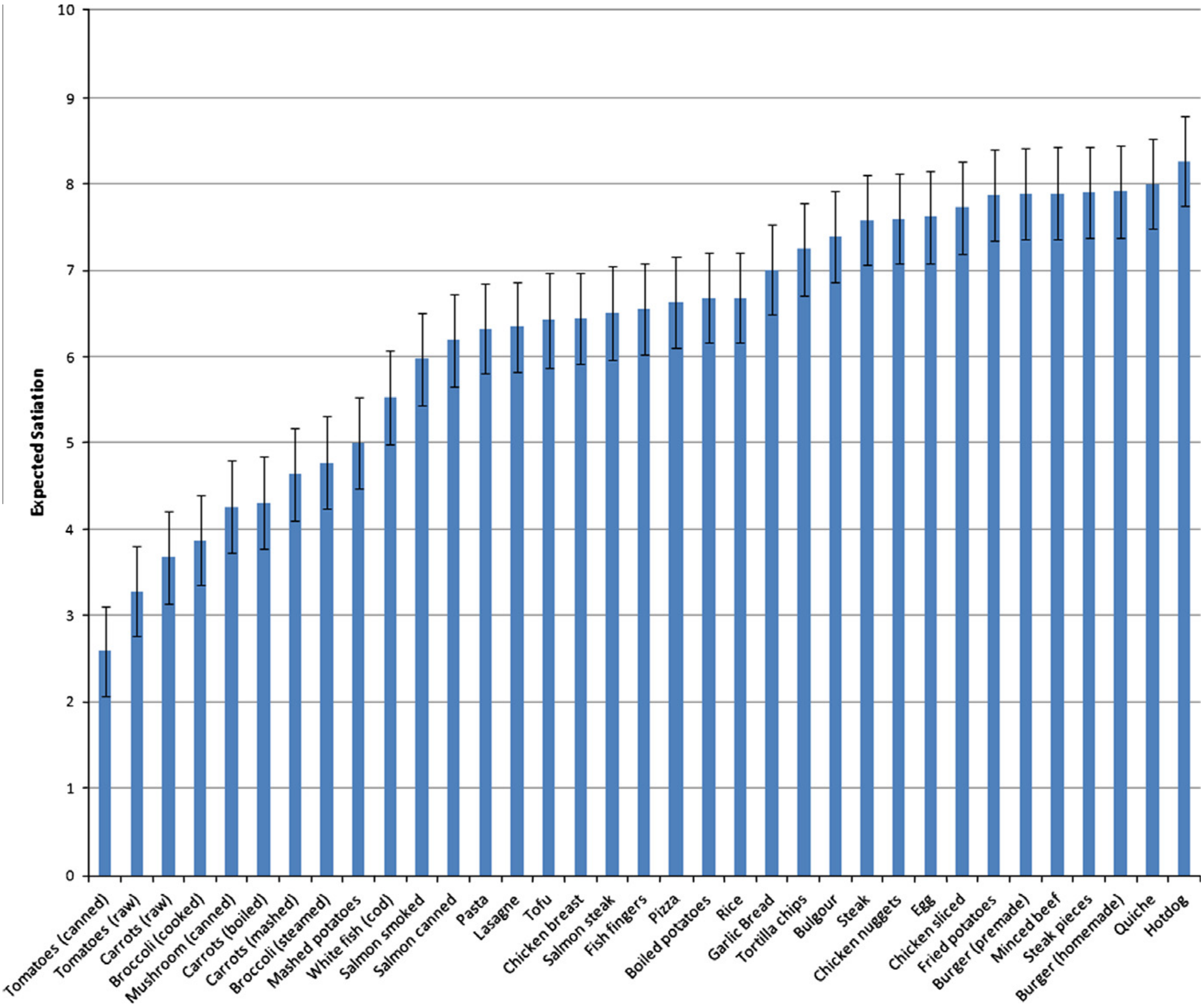


Fig. 5. Average expected satiation scores on a 100-mm VAS scale, (±Standard Error) for 35 the food items.

$p = 0.04$) and food chewiness ($R^2 = 0.15$, $p < 0.01$), whereas the other sensory attributes were not related to expected satiation. Four of the seven oral processing characteristics were significantly related to expected satiation, the number of swallows ($R^2 = 0.14$, $p = 0.03$), bite size (negative correlation $R^2 = 0.14$, $p = 0.03$), oral exposure time ($R^2 = 0.11$, $p = 0.05$) and eating rate (negative correlation; $R^2 = 0.27$, $p < 0.001$). Therefore, foods that have a higher expected satiation were consumed with smaller bite sizes and were chewed for longer, than foods that were not expected to be as filling.

Relationship between oral processing and food liking

Participants in the oral processing task rated their liking for the 50 g portion of each food after they had consumed each food item. Liking for each food was correlated with the sensory profile, macronutrient content and oral processing measures to explore relationships. The liking was positively correlated with the overall flavour of the foods ($R^2 = 0.21$, $p = 0.01$), saltiness, ($R^2 = 0.16$, $p = 0.02$) and savouriness ($R^2 = 0.17$, $p = 0.01$) indicating that foods with higher flavour tended to be rated higher in liking. There was a negative relationship between liking and fiber content ($R^2 = 0.36$, $p = 0.03$) and a positive, non-significant, relationship with fat content ($R^2 = 0.11$, $p = 0.05$). We hypothesized that the more liked foods would be eaten more quickly, in larger bites and would be chewed differently than less liked food items. However, there were no relationships between food liking and the oral processing characteristics of the foods indicating that the hedonic properties of the food did not influence the bites, chews, swallows or time in mouth for any of the 35 foods. Liking was not correlated with the participants rating of expected satiation for each food item ($R^2 = 0.02$, $p = 0.42$), indicating that the two measures differentiate the food items independently.

Discussion

The current study builds on previous work on oral processing of everyday foods and demonstrates that there are many important differences in oral processing characteristics among solid savoury meal components that are worth considering in the context of energy intake. The observed number of bites/chews/swallows varied 6–18-fold between softly textured foods that required little chewing and harder textured foods that required many chews before swallowing. The number of bites, chews, and swallows were

Author's personal copy

highly correlated with derived measures such as bite size (2–10 g), eating rate (12–101 g/min), chews/bite (3–31), and oro-sensory exposure time (28–349 s/50 g). The high variability in number of chews, bites and oro-sensory exposure time among the 35 foods, indicates differences in the rate of energy intake when these foods are consumed in a regular hot meal and may provide an opportunity to design meals with lower or higher satiating efficiencies through substitution of these components. The correlations between many of the measured variables were considerably lower than those reported elsewhere, (Viskaal-van Dongen et al. 2011) and this decrease can be explained by the much narrower range of food textures (only solids) chosen compared to those previously studied (liquids and solids). Nonetheless, many of the inter-relationships reported in the current paper were significant.

The current results are in line with other reported data on bite size, number of chews, eating rate, and chews/bite of solid foods. Ioakimidis et al. (2011) found an average bite size (mouthful weight) for a chicken/vegetable meal of about 7–8 g/bite, whereas we found typical bite sizes of 5–8 g. In the study of Ioakimidis et al. (2011) it took the subjects about 800 chews for an average of 264 g (=301 chews/100 g) of food, which is similar to the current average of 160 chews/50 g food (=320 chews/100 g). Viskaal-van Dongen et al. (2011) also found that eating rates of solid foods varied between 10 and 100 g/min, which is equivalent to the eating rates in this study. Ioakimidis et al. (2011) observed that about 80% of the bites consisted of a series of 8–20 chews/bite, whereas in this study this is the case for 62% of the bites. The actual ranges for number of chews/bite in the studies coincide. The similarity between the results of Ioakimidis et al. (2011) and this study is striking, as their study comprised one solid meal for 6 women, and the current study comprised 35 single solid foods for 10 women and 5 men.

Whereas number of chews, bites and swallows were highly correlated, chewing rate stands out in its relative constancy between various foods. Foods with a different required number of chews and bites were chewed at a rate of approximately 1 chew/s. This indicates that chewing follows a pattern that is more or less automatic and is less dependent of the sensory or physical–chemical characteristics of the foods. This value is in the range of values reported in the literature, where values were reported from 1 to 1.8 chews/s (Bellisle & Le Magnen, 1981; Spiegel et al., 1993; Hennequin et al., 2005; Ioakimidis et al., 2011). This observation concurs with the suggestion of Ioakimidis et al. (2011), that the "human chewing pattern is relatively stereotyped". In a recent paper, Loret et al. (2011) demonstrated that subjects had their own mastication strategy for food bolus formation across a range of different cereals that had similar physical properties at the point of swallowing.

As expected, more softly textured foods required less chewing, were consumed faster and resulted in less oro-sensory exposure time. The mashed foods required less chewing and were consumed very fast. Most processed foods had softer textures, but this was not always the case. Tortilla chips, which are highly processed food, had the lowest eating rate in this study. This finding indicates that food processing *per se* does not always lead to faster eating rates and lower oro-sensory exposure times.

The relationship between the nutritional/chemical composition of the foods and the oral processing characteristics showed that more energy dense products required more chews, and resulted in a longer oro-sensory exposure times. By contrast, higher water content led to the opposite trend and resulted in less chews and a shorter oro-sensory exposure time. These results make sense as a higher energy density will usually coincide with a lower water content and relative more solid mass. A more solid mass will usually require more chewing. From this perspective it is somewhat surprising that higher macronutrient contents and higher fiber levels had no consistent relationship with number of chews and oro-sensory exposure time. One explanation could be that the way of processing or preparation is more important for variance in oral processing characteristics than separate macronutrient contents *per se*. Also, carbohydrates are easily dissolvable in water and may have softer textures also with higher concentrations. A similar notion applies for fat, which may be associated with creaminess and smoothness (e.g. Kahkonen & Tuorila, 1999). There was also a lack of correspondence between the taste properties of the foods and the way in which they were orally processed. The current trial did not control for the separate effects of oral processing behavior and macro-nutrient content, choosing instead to use a wide selection of everyday food items. Further research should investigate whether there is an optimum macronutrient profile, which provides the composition to sustain satiety while simultaneously providing a structure that leads to longer oral processing times.

With regard to differences in the physical–chemical composition of foods and the effort and time required for oral processing, Hutchings and Lillford (1988) previously proposed the food oral process model to explain the breakdown path for different food types. This approach summarized food oral breakdown on three dimensions of degree of structure, degree of lubrication needed for swallow and the time required in mouth to process the bite into a bolus that can be swallowed. More recently, Loret et al. (2011) have studied food bolus consistency before swallowing and food particles suspended in a large saliva fraction (approximately 50%) at the point of swallow. The rate of saliva flow controlled the number of chewing cycles and the time in mouth required before an individual chose to swallow. Taken together, these findings can be applied to better explain the variation in oral processing time we have observed across the 35 food items in the current study, as a function of structure, lubrication and time required to form a bolus for swallowing. A deeper understanding of the physical–chemical processes involved in the trajectory of oral breakdown may help in the design of foods with a longer oral exposure time and a greater requirement for chewing that result in earlier satiation and reduced energy intake. Focusing on a foods oral exposure time as a function of its structure, may lead to a twofold effect of increasing the oral exposure time to promote interaction with the sensory systems while simultaneously slowing the rate at which calories are consumed within a meal.

With respect to the association between sensory characteristics of the foods and the oral processing characteristics, the texture properties had more effect than taste properties. The perceived chewiness was correlated to total number of chews and both chewiness and firmness were related to the oro-sensory exposure time. The perceived firmness refers to the force required for first bite, whereas chewiness reflects the inherent structure within the product and the length of time and amount of work required to process the food to a bolus that can be swallowed safely (Loret et al., 2011).

Variation in expected satiation scores were observed for each food with a threefold difference in the range between foods with low expected satiation and highly filling foods and such as hotdogs, quiches and other energy dense foods. It is not surprising that the lowest expected satiation rating was for a softly textured foods with a low amount of energy, (i.e. vegetables). Expected satiation was positively related to energy density, fat and protein content of the foods, but not to the carbohydrate or fiber content. This may be related to the notion that within the 35 experimental foods, there was a larger variation in protein and fat content than in carbohydrate and fiber content (Table 1). Hot savoury meals tend to have a higher percentage of fat and protein than the other meals of the day. Expected satiation was also related to the perceived saltiness and chewiness of the food products, and a number of oral processing characteristics, such as oro-sensory exposure time and eating rate. This indicates that subjects may have an

Author's personal copy

intuitive knowledge that foods that have a higher sensory intensity or require longer chewing have a higher satiating efficiency. This idea is in-line with the results of the studies of (Weijzen, Zandstra, Alfieri, & de Graaf, 2008) and Bolhuis et al. (2011) on the effect of sensory intensity on *ad libitum* food intake, and with a large number of studies on negative association between oro-sensory exposure time *ad libitum* food intake (see for review de Graaf, 2011). Recent findings that correlate sensory properties to expected satiation have also shown that higher thickness predicts higher expected satiation in both yogurts and soups (Hogenkamp et al., 2010). These results indicate a key role for food texture in informing consumers expectations of satiation, and this likely a learned association between the sensory properties and experiences of fullness post consumption. The measure of expected satiation in the current trial is a rough proxy estimate for actual fullness, and as such we exercise caution in drawing inferences in the absence of actual fullness data.

The notion that a longer oro-sensory exposure time is related to a higher satiating efficiency is congruent with the idea that the taste system serves as a nutrient sensing system (Yarmolinsky, Zuker, & Ryba, 2009). With liquids and with foods that are eaten quickly this system is bypassed and is not capable of orally metering calorie intake. The taste system informs that brain and the GI tract about the inflow of macronutrients through the cephalic phase responses. The cephalic phase response requires a considerable amount of time for taste stimulation and/or chewing as shown in the studies by Teff (2010). Liquids do not elicit the same cephalic phase response as solids (Teff, 2010). This idea is also in line with a recent number of studies that have shown that slower eating results in higher levels of satiety hormones such a GLP-1 and PYY, and a stronger suppression of ghrelin levels, which is a hormone that increases hunger (Kokkinos et al., 2010; Li et al., 2011).

If foods can be designed to give rise to earlier meal termination, this may be an effective way to reduce total energy intake across a day. Many studies have shown that people do not change their energy intake from meal to meal, i.e. a smaller or larger intake at breakfast does not lead to compensation later in the day (e.g. de Castro, 1988). This lack of compensation has been shown to occur over a longer term basis (e.g. De Graaf, Hulshof, Weststrate, & Hautvast, 1996; Kendall, Levitsky, Strupp, & Lissner, 1991). Rolls, Roe, and Meengs, (2006), (2007) showed in two recent studies that decreasing or increasing energy density and portion size led to sustained decreases and increases in energy intake. Levitsky and Pacanowski (2011) has demonstrated that total daily energy intake could be lowered by replacing a lunch meal with a lower calorie version of a lunch meal over a period of 10 days, without any sign of caloric compensation. These results are encouraging and indicate that achieving earlier satiation within meals could lead to meaningful decreases in overall energy intake that are not compensated for in the long term. By contrast, the findings from the current study may potentially present an opportunity to optimise the texture profile of foods for older consumers to encourage consumption of food and improve energy and nutrient intakes in this vulnerable population.

The concept of eating rate is not only a property of a food, but can also be considered as a property of a person. There is evidence that eating rate is involved in the development of obesity from both perspectives. First, there is substantial evidence that adding liquid calories (fast foods) leads to an higher energy intakes and body weights (e.g. Chen et al., 2009; Malik, Popkin, & Bray, 2010; Schulze et al., 2004), whereas there is also evidence that omitting liquid calories from the diet leads to a lower energy intake and body weights (Chen et al., 2009). This is not true for solid calories (Chen et al., 2009), since most of daily energy intake comes from solid savoury meals that cannot be removed as easily as unnecessary liquid calories. On the other person related side of eating rate, there have been reports that eating faster can lead to obesity (Otsuka et al., 2006; Sasaki, Katagiri, Tsuji, Shimoda, & Amano, 2003) and that slower eating rate can be used to reduce food intake (Martin et al., 2007). In a recent study of Llewellyn, van Jaarsveld, Boniface, Carnell, and Wardle (2008), it was suggested that already in 5–10 y old children that eating rate was a heritable phenotype related to the body mass index. Within this context it is worthwhile to note a recent study of Ford, who trained obese children to eat more slowly, which lead to sustained changes in behavior and energy intake (Ford et al., 2010). Therefore, eating behaviors may be heritable, but can be changed. These two perspectives put eating rate and oro-sensory exposure at the heart of the regulation of energy intake.

In summary, alternative components of a hot meal differ considerably in their oral processing characteristics. These characteristics such as number of chews, bites, and swallows can be measured reliably using the current approach and there are clear differences among everyday savoury meal components. A higher number of chews and bites generally co-vary with longer oro-sensory exposure times and lower eating rates. The oral processing characteristics are primarily determined by texture related factors, where softer textures result in less chewing activity and lower oro-sensory exposure times. This implies a need to focus on the design of foods with structures that lead to longer oral exposure and times that cue satiation earlier to reduce calorie intake. The next question is then whether or not alternative food structures with lower or higher satiating efficiencies will lead to higher and lower *ad libitum* food intake within a meal.

References

Bellisle, F., & Le Magnen, J. (1981). The structure of meals in humans. Eating and drinking patterns in lean and obese subjects. *Physiology and Behavior, 27*, 649–658.

Bellisle, F., Lucas, F., Amrani, R., & LeMagnen, J. (1984). Deprivation, palatability and the micro-structure of meals in human subjects. *Appetite, 5*, 85–94.

Bolhuis, D. P., Lakemond, C. M., de Wijk, R. A., Luning, P. A., & de Graaf, C. (2011). Both longer oral sensory exposure to and higher intensity of saltiness decrease *ad libitum* food intake in healthy normal-weight men. *Journal of Nutrition, 141*, 2242–2248.

Bolton, R. P., Heaton, K. W., & Burroughs, L. F. (1981). The role of dietary fiber in satiety, glucose, and insulin. Studies with fruit and fruit juice. *American Journal of Clinical Nutrition, 34*, 211–217.

Brunstrom, J. M., Shakeshaft, N. G., & Scott-Samuel, N. E. (2008). Measuring expected satiety in a range of common foods using a method of constant stimuli. *Appetite, 51*, 604–614.

Burger, K. S., Fisher, J. O., & Johnson, S. L. (2011). Mechanisms behind the portion size effect. Visibility and bite size. *Obesity, 19*, 546–551.

Chen, L., Appel, L. J., Loria, C., Lin, P. H., Champagne, C. M., Elmer, P. J., Ard, J. D., Mitchell, D., Batch, B. C., Svetkey, L. P., & Caballero, B. (2009). Reduction in consumption of sweetened-beverages is associated with weight loss. The PREMIER trial. *American Journal of Clinical Nutrition, 89*, 1299–1306.

De Castro, J. M. (1988). Physiological, environmental, and subjective determinant of food intake in humans. A meal pattern analysis. *Physiology and Behavior, 44*, 651–659.

De Graaf, C. (2000). Nutritional definitions of the meal. In H. L. Meiselman (Ed.), *Dimensions of the meal. The science, culture, business and art of eating* (pp. 47–60). USA: Aspen Publishers Inc. Gaithersburg MD.

De Graaf, C., Hulshof, T., Weststrate, J. A., & Hautvast, J. G. (1996). Non-absorbable fat (sucrose polyester) and the regulation of energy intake and body weight. *American Journal of Physiology, 270*, R1386–R1393.

De Graaf, C. (2011). Why liquid energy results in overconsumption. *Proceedings of the Nutrition Society, 70*, 162–170.

De Graaf, C., Stafleu, A., Staal, P., & Wijne, M. (1992). Beliefs about the satiating effect of bread with spread varying in macronutrient content. *Appetite, 18*(2), 121–128.

De Graaf, C., & Kok, F. J. (2010). Slow food, fast food and the control of food intake. *Nature Reviews Endocrinology, 6*, 290–293.

DiMeglio, D. P., & Mattes, R. D. (2000). Liquid versus solid carbohydrate. Effects on food intake and body weight. *International Journal of Obesity Related Metabolic Disorders, 24*, 794–800.

Fisher, J. O., Rolls, B. J., & Birch, L. L. (2003). Children's bite size and intake of an entrée are greater with large portion than with age appropriate or self-selected portions. *American Journal of Clinical Nutrition*, 1164–1170.

Flood-Obbagy, J. E., & Rolls, B. J. (2009). The effect of fruit in different forms on energy intake and satiety at a meal. *Appetite, 52*, 416–422.

Author's personal copy

Ford, A. L., Bergh, C., Sodersten, P., Sabin, M. A., Hollinghurst, S., Punt, L. P., & Shield, J. P. H. (2010). Treatment of childhood obesity by retraining eating behaviour. Randomized controlled trial. *British Medical Journal, 340*, b5388. http://dx.doi.org/10.1136/bmj.b5388.

Green, S. M., Delargy, D., Joanes, J. E., & Blundell, J. E. (1997). A satiety quotient. A formulation to assess the satiating effect of food. *Appetite, 29*(3), 291–304.

Haber, G. B., Heaton, K. W., Murphy, D., & Burroughs, L. F. (1977). Depletion and disruption of dietary fibre. Effects on satiety, plasma glucose, and serum-insulin. *Lancet, 2*, 679–682.

Hennequin, M., Allison, P. J., Veyrune, J. L., Faye, M., & Peyron, M. (2005). Clinical evaluation of mastication; validation of video vs electromyography. *Clinical Nutrition, 24*, 314–320.

Hogenkamp, P. S., Mars, M., Stafleu, A., & de Graaf, C. (2010). Intake during repeated exposure to low- and high-energy-dense yoghurts by different means of consumption. *American Journal of Clinical Nutrition, 91*, 841–847.

Hutchings, J. B., & Lillford, P. J. (1988). The perception of food texture. The philosophy of the oral breakdown path. *Journal of Texture Studies, 19*(2), 103–115.

Ioakimidis, I., Zandian, M., Eriksson – Marklund, L., Bergh, C., Grigoriadis, A., & Sodersten, P. (2011). Description of chewing and food intake over the course of a meal. *Physiology and Behavior, 104*, 761–769.

Kokkinos, A., Le Roux, C. W., Alexiadou, K., Tentolouris, N., Vinvent, R. P., Kyriki, D., Perrea, D., Ghatei, M. A., Bloom, S. R., & Katsilambros, N. (2010). Eating slowly increases the postprandial response of the anorexigenic gut hormones, peptide YY and glucagon-like-peptide-1. *Journal of Clinical Endocrinology and Metabolism, 95*, 333–337.

Leidy, H. J., Apolzan, J. W., Mattes, R. D., & Campbell, W. W. (2010). Food form and portion size affect postprandial appetite sensation and hormonal responses in healthy, nonobese, older adults. *Obesity, 18*, 293–299.

Levitsky, D. A., & Pacanowski, C. (2011). Losing weight without dieting. Use of commercial foods as meal replacements for lunch produces an extended energy deficit. *Appetite*, 311–317.

Llewellyn, C. H., van Jaarsveld, C. H., Boniface, D., Carnell, S., & Wardle, J. (2008). Eating rate is a heritable phenotype related to weight in children. *American Journal Clinical Nutrition, 88*, 1560–1566.

Li, J., Zhang, N., Li, Z., Li, R., Li, C., & Wang, S. (2011). Improvement in chewing activity reduces energy intake in one meal and modulates plasma gut hormone concentrations in obese and lean Chinese men. *American Journal of Clinical Nutrition, 94*, 709–716.

Loret, C., Walter, M., Pineau, N., Peyron, M. A., Hartmann, C., & Martin, N. (2011). Physical and related sensory properties of a swallowable bolus. *Physiology and Behaviour, 104*, 855–864.

Kahkonen, P., & Tuorila, H. (1999). Consumer responses to reduced and regular fat content in different products. Effects of gender, involvement and health concern. *Food Quality and Preference, 10*, 83–91.

Kendall, A., Levitsky, D. A., Strupp, B. J., & Lissner, L. (1991). Weight loss on a low-fat diet. Consequence of the imprecision of the control of food intake in humans. *American Journal of Clinical Nutrition, 53*, 1124–1129.

Malik, V. S., Popkin, B. M., & Bray, G. A. (2010). Sugar sweetened beverages and risk of metabolic syndrome and type 2 diabetes. Epidemiological evidence. A meta analysis. *Diabetes Care, 33*, 2477–2488.

Martin, C. K., Anton, S. D., Walden, H., Arnett, C., Greenway, F. L., & Williamson, D. A. (2007). Slower eating rate reduces the food intake of men, but not women. Implications for behavioral weight control. *Behavioral Research Therapy, 45*, 2349–2359.

Mourao, D. M., Bressan, J., Campbell, W. W., & Mattes, R. D. (2007). Effects of food form on appetite and energy intake in lean and obese young adults. *International Journal of Obesity, 31*, 1688–1695.

Otsuka, R., Tamakoshi, K., Yatsuya, H., Murata, C., Sekiya, A., Wada, K., et al. (2006). Eating fast leads to obesity. Findings based on self administered questionnaires among middle aged Japanese men and women. *Journal of Epidemiology, 16*, 117–124.

Rolls, B. J. (2010). Plenary lecture 1. Dietary strategies for the prevention and treatment of obesity. *Proceedings of the Nutrition Society, 69*, 70–79.

Rolls, B. J. (2009). The relationship between dietary energy density and energy intake. *Physiology and Behavior, 97*, 609–615.

Rolls, B. J., Roe, L. S., & Meengs, J. S. (2006). Reductions in portion size and energy density of foods are additive and lead to sustained decreases in energy intake. *American Journal of Clinical Nutrition, 83*, 11–17.

Rolls, B. J., Roe, L. S., & Meengs, J. S. (2007). The effects of large portion sizes on energy intake is sustained for 11 days. *Obesity, 15*, 1535–1543.

Sasaki, S., Katagiri, A., Tsuji, T., Shimoda, T., & Amano, K. (2003). Self-reported rate of eating correlates with body mass index in 18-y-old Japanese women. *International Journal of Obesity, 27*, 1405–1410.

Schulze, M. B., Manson, J. E., Ludwig, D. S., Colditz, G. A., Stampfer, M. J., Willett, W. C., & Hu, F. B. (2004). Sugar sweetened beverages, weight gain and incidence of type 2 diabetes in young and middle aged women. *Journal of the American Medical Association, 292*, 927–934.

Smit, H. J., Kemsley, E. K., Tapp, H. S., & Henry, C. J. K. (2011). Does prolonged chewing reduce food intake? Fletcherism revisited. *Appetite*, 295–298.

Spiegel, T. A., Kaplan, J. M., Tomassini, A., & Stellar, E. (1993). Bite size, ingestion rate, and meal size in lean and obese women. *Appetite, 21*, 131–145.

Stellar, E., & Shrager, E. E. (1985). Chews and swallows and the microstructure of eating. *American Journal of Clinical Nutrition, 42*, 973–982.

Teff, K. L. (2010). Cephalic phase pancreatic polypeptide responses to liquid and solid stimuli in humans. *Physiology and Behavior, 99*, 317–323.

Van Strien, T., Frijters, J. E., Roosen, R. G., Knuiman-Hijl, W. J., & Defares, P. B. (1985). Eating behavior, personality traits and body mass in women. *Addictive Behaviors, 10*, 333–343.

Viskaal-van Dongen, M., Kok, F. J., & de Graaf, C. (2011). Eating rate of commonly consumed foods promotes food and energy intake. *Appetite, 56*, 25–31.

Viskaal-van Dongen, M., Kok, F. J., & de Graaf, C. (2012). Taste nutrient relations in commonly eaten foods. *British Journal of Nutrition*.

Weijzen, P. L. G., Zandstra, E. H., Alfieri, C., & de Graaf, C. (2008). Effects of complexity and intensity on sensory specific satiety and food acceptance after repeated consumption. *Food Quality and Preference, 19*, 349–359.

Weijzen, P. L., Smeets, P. A., & de Graaf, C. (2009). Sip-size of orangeade. Effects on intake and on sensory specific satiation. *British Journal of Nutrition, 102*, 1091–1097.

Yarmolinsky, D. A., Zuker, C. S., & Ryba, N. J. P. (2009). Common sense about taste. From mammals to insects. *Cell*, 234–244.

Zijlstra, N., Mars, M., de Wijk, R. A., Westerterp-Plantenga, M. S., & de Graaf, C. (2008). The effect of viscosity on *ad libitum* food intake. *International Journal of Obesity, 32*, 676–683.

Zijlstra, N., de Wijk, R. A., Mars, M., & de Graaf, C. (2009). Effects of bite size and oral processing time of a semisolid food on satiation. *American Journal of Clinical Nutrition, 90*, 269–275.

View publication stats