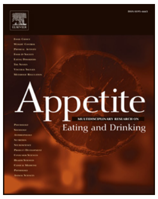
Appetite 131 (2018) 36–43

Contents lists available at ScienceDirect

Appetite

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



How does fatty mouthfeel, saltiness or sweetness of diets contribute to dietary energy intake?

David N. Cox*, Gilly A. Hendrie, Haidee J. Lease, Megan A. Rebuli, Mary Barnes[1]

CSIRO Health and Biosecurity, Adelaide, SA 5000, Australia

ARTICLE INFO

Keywords:
Sensory
Taste
Sweet
Salty
Fatty-mouthfeel
Diet
Energy intake
Adults
Children

ABSTRACT

As “taste” is a primary driver of food choice, the objective of this study was to understand how the sensory properties of diets relate to energy intake (EI). A database of 720 frequently consumed foods, described by a trained panel for basic tastes (sweetness, saltiness) and fatty mouthfeel, was systematically applied to all foods reportedly consumed in 24hr recalls as part of the 2011–2012 Australian National Nutrition and Physical Activity Survey ($n = 12,153$ adults and children). Food groups were classified according to the Australian Guide to Healthy Eating, and their contribution to total nutrient and sensory intake estimated. There were significant positive correlations between the nutrient and sensory properties of diets, for example, for adults, EI and fatty mouthfeel $r = 0.740$; EI and saltiness $r = 0.623$ and EI and sweetness $r = 0.517$ (all $p < 0.01$). Core foods (e.g. fruits, vegetables, grains, dairy) can provide similar sensory stimulation whilst being of lower energy content than discretionary foods (e.g. confectionary, snacks). Regression models in adults, controlling for age, sex and BMI, revealed that fatty mouthfeel ($\beta = 0.492$), saltiness ($\beta = 0.161$) and sweetness ($\beta = 0.138$) were significant predictors of EI, explaining 56% variance ($p < 0.01$). Similar results were found for children. Fatty mouthfeel was the primary driver of energy intake but such sensory stimulation can be derived from core (e.g. dairy foods), rather than discretionary foods, at lower energy content.

1. Introduction

There are many drivers of food choice that may account for the variation in dietary energy intake of individuals, including cost, convenience, health, personal relationships, values (e.g. symbolism and ethics) and taste. However taste is a primary consideration for most people in nearly all food and drinking settings (Sobal, Bisogni, Devine, & Jastran, 2006). By ‘taste’ lay people tend to mean the broad sensory properties of foods (Sobal et al., 2006), including the basic tastes: sweet, sour, salty, bitter and umami; textures (or mouthfeel); smell (aroma); spicy or cooling properties (chemethesis) and flavours (specific aromas and combinations of all sensory modalities). Past literature has identified relationships between tastes, fat perception and food intake. Infants are born with a preference for sweet taste thought to be derived from an association between sweet taste and energy intake (Steiner, 1979). Neuroscience has identified the importance of sweetness as a reward (Peciña, Smith, & Berridge, 2006) and also its role in satiety and satiation (Low, Lacy, & Keast, 2014). Infants soon develop a liking for saltiness, which was thought to be useful for when this mineral was once rare (Mennella, 2014). Furthermore, evidence shows salty foods to be highly palatable (Mattes, 1997) with salt masking unpalatable bitterness (Hayes, Sullivan, & Duffy, 2010). Taste has a role in satiation, for example, saltiness exposure and intensity decreased food intake amongst normal weight men (Bolhuis, Lakemond, de Wijk, Luning, & de Graaf, 2011, 2012). There is also suggestive evidence that the fatty mouthfeel texture (fattiness) is associated with innate neural reward activations (Grabenhorst, Rolls, Parris, & d'Souza, 2009) and is thought to be important because it may signal that the food is high in dietary energy (Drewnowski, 1998). While useful in past times of dietary scarcity, these sensory cues, in the current environment of plenty, may help to explain excessive energy intake, overweight and obesity. Different approaches are beginning to measure the sensory characteristics of commonly consumed foods, with examples from France (Martin, Visalli, Lange, Schlich, & Issanchou, 2014), The Netherlands and Malaysia emerging (Pey et al., 2018). French data (Lampuré et al., 2016) suggest that liking for dietary fattiness is more important than liking for sweet or salt in terms of risk of developing obesity. However, the exact role of tastes and fattiness on weight status

---

* Corresponding author.
E-mail addresses: david.cox@csiro.au (D.N. Cox), gilly.hendrie@csiro.au (G.A. Hendrie), haidee.lease@csiro.au (H.J. Lease), megan.rebuli@csiro.au (M.A. Rebuli), mary.barnes@flinders.edu.au (M. Barnes).

[1] Current address: Flinders University, Bedford Park, SA 5042, Australia.

https://doi.org/10.1016/j.appet.2018.08.039
Received 10 April 2018; Received in revised form 28 August 2018; Accepted 30 August 2018

is not well understood (Cox, Hendrie, & Carty, 2016) and less is known about how tastes (i.e. saltiness, sweetness) or the mouthfeel (i.e. fattiness) might be associated with dietary energy intake.

Tastes can signal nutrient content of foods particularly amongst un- or minimally processed foods, although the relationship is weaker for highly processed foods (van Dongen, van den Berg, Vink, Kok, & de Graaf, 2012). Analysis of the sensory characteristics of 237 processed foods in the USA (van Langeveld et al., 2017) found that, whilst sweet taste was associated with mono- and di-saccharide content, it was not correlated with energy content of foods. There is a need to further understand types of food and the relationships between their sensory characteristics and nutrient content. The current paper utilizes the established dietary recommendation's distinctions of core foods (micronutrient rich e.g. fruits, vegetables, grains, dairy) and discretionary foods (micro-nutrient poor but possibly energy dense and highly processed foods e.g. confectionary and sugar-sweetened beverages). Further details are given in the methods section below.

Recent studies have sought to measure liking for fatty, salty and sweet sensations (Urbano et al., 2016) and infant exposure to sweetness, fattiness and subsequent consumption (Yuan et al., 2016). Preliminary analysis (Cox et al., 2013) of children's reported dietary intakes from the Australian National Children's Nutrition and Physical Activity Survey 2007 found that salty taste was most consistently and strongly associated with children's adiposity; however, dietary energy intakes were not investigated. More recent data in a large sample of Australians found that healthier diets, as defined by a validated diet score referring to dietary recommendations, were associated with increased sweetness and lower saltiness but not fatty mouthfeel (Cox, Hendrie, & Lease, 2018). A comprehensive review (Cox et al., 2016) of the relationship between sensory characteristics of foods and the influence of basic tastes and fattiness on weight status found little evidence of a relationship between sweet, salty, sour or bitter tastes and weight status. There was some evidence for an association for fat hedonics (liking) and a preference for fat and increased weight status. This review highlighted a need for more rigorous measures of sensory characterisation and dietary intake to better understand whether the sensory characteristics of foods and diets influence energy intake and weight status.

The current study has novelty because it investigates diet (rather than just selected foods), includes the texture fatty mouthfeel (not just basic tastes) and seeks to predict (statistically) reported dietary energy intake (not, for example, hedonics) utilizing a unique tool and large datasets. The CSIRO Sensory–Diet database is a unique and validated tool for measuring the sensory characteristics of Australian foods (Lease, Hendrie, Poelman, Delahunty, & Cox, 2016) and has recently been updated and linked to a food nutrient composition database compatible with the latest Australian national nutrition survey. The database is comprehensive, and sensory characteristics of foods are objectively measured. Combining these data with national nutrition survey data allows the relationships between fatty, salty or sweet foods and total energy intake to be determined.

The primary aim of this paper was to use the CSIRO Sensory-Diet database to describe the sensory profile (sweetness, saltiness, and fatty mouthfeel) of diets reported by Australian adults and children, with a particular focus on the relationship between sensory characteristics and total energy intake.

More specifically, the objectives were to:

1. Determine whether sweetness, saltiness or fatty mouthfeel predict (statistically) total energy in Australian adults and children, independent of demographics.
2. Examine the contribution of core food groups and discretionary foods and beverages to the total sensory profile of the diet and how food groups vary in the sensations they provide relative to their composition and energy content.

2. Materials and methods

2.1. Dietary intake data

Dietary intake data from the National Nutrition and Physical Activity Survey conducted as part of the 2011/12 Australian Health Survey was augmented with the CSIRO Sensory-Diet database to examine the sensory properties of Australians' diets.

The Australian Health Survey was conducted by the Australian Bureau of Statistics (ABS) in 2011–2012, reaching 32,000 people (25,000 households). The secondary analysis conducted for the current study utilised data collected from the 12,153 respondents completing the National Nutrition and Physical Activity Survey (NNPAS). Given the complexity of the Australian Health Survey, a more detailed description of the sampling framework and data collection methods is available in the comprehensive ‘Users Guide’ (Australian Bureau of Statistics, 2011–13).

Briefly, the method used to collect the dietary intake data as part of the NNPAS was two 5-phase, 24-h recalls, where respondents were asked to recall the previous 24 h intake of food, beverages and dietary supplements (see (Australian Bureau of Statistics, 2011–13) for detailed descriptions of the data collection process). The USDA Automated Multiple-Pass Method developed by the United States Department of Agriculture was adapted by the ABS together with Food Standards Australia and New Zealand (FSANZ). The first recall was conducted face-to-face with a trained interviewer, and the second dietary recall attempted with all respondents at least 8 days later via a telephone interview. For this study the first day of recall only was used. Using day 1 of the survey's dietary data meant inclusion of the entire sample of 12,153 respondents. For children aged 2 years to less than 15 years the interview was conducted primarily with a parent or guardian, and children were encouraged to participate. Parental consent was granted to interview respondents aged 15–17 years, while some parents opted to provide this information on the child's behalf. A food model booklet was provided to participants to assist in the estimation of portion size and quantities of recalled items.

Nutrient intake data was provided for each food, beverage or supplement item recalled using a nutrient composition database specifically developed by FSANZ (AUSNUT, 2011–13). Recalled items were also coded into a hierarchy of food classification – at the major (2 digit), sub-major (3-digit), minor (5-digit) and descriptive 8 digit level. The 8 digit level code was used to join the food item to the corresponding sensory data.

2.2. Sensory-Diet database

The CSIRO Sensory-Diet database currently comprises over 720 foods characterized by a trained sensory panel (using an adaptation of the Spectrum method (Meilgaard, Civille, & Carr, 2007a) for five basic tastes (sweet, sour, bitter, salt and umami), as well as fatty mouthfeel, hardness, cohesiveness of mass, moistness and flavour strength. Each modality was rated on a 100 point unstructured line scale anchored at 5% and 95%. A systematic protocol for assigning sensory values from characterized food to other similar but un-characterized foods has been established to allow for completeness across all foods and beverages consumed by the Australian population and reflective of all foods within the nutrient composition database (Lease et al., 2016). This paper focuses on three sensory characteristics of foods and diets: sweet, salty and fatty mouthfeel.

2.3. Secondary analysis methodology

Food and beverage nutrient data was linked to the sensory data from the CSIRO Sensory-Diet database using the unique 8 digit level food code. There are over 5000 unique food codes (with many as flavour variations of foods) in the AUSNUT database and 720 foods that have been tested for their sensory profile. Therefore to complete the database, the closest match was chosen using a validated method (Lease et al., 2016) and the sensory data applied to foods at the 8 digit level.

To understand the contribution of nutrients and sensory characteristics from specific food groups to the total diet, we assigned all foods and beverages to its corresponding food group consistent with the Australian Guide to Healthy Eating (National Health and Medical Research Council) and Australian Dietary Guideline recommendations (National Health and Medical Research Council, 2013). The food groups included core foods: fruit (fresh, dried and 100% fruit juice); vegetables (fresh, canned, frozen and mixed dishes); meat and alternatives (beef, lamb, pork, poultry, egg, tofu and other vegetarian alternatives); dairy and alternatives (milk, cheese, yoghurt and their non-dairy alternatives); grains (bread, cereal, rice, pasta, breakfast cereal and grain based dishes); healthy fats and oils (margarine, oils, and avocado); and other foods not fitting into one of these groups (such as condiments, herbs and spices). Discretionary foods (for example cakes, biscuits, pies, fried potatoes, chocolate, confectionary, sugar sweetened beverages and alcohol) received particular attention relative to the core foods defined above.

All data were weighted to reflect the demographic structure of the Australian population, and weighted means presented for the population and demographic descriptive statistics. Permission to gain access to the survey database and to conduct this secondary analysis was obtained from the ABS prior to commencing the work.

2.4. Statistical analysis

Total sensory amount per food item consumed was calculated as the sensory value of the food multiplied by the grams consumed. The total sensory profile of the diet was the sum of the sensory values for all foods and beverages consumed. To control for total food or energy intake, the density of diets was presented as the total dietary sensory score per 1000 kJ, and termed 'sensory density' (analogous to nutrient density - see worked example below).

Step 1: Sample of simplified dietary data from one individual for one day of intake and sensory data for sweetness.

Food list	Amount (g)	Kilojoules (kj)	Sweetness value (out of 100)
Apple	120 g	245kj	35.33
Bread	60 g	591kj	40.00
Honey	15 g	212kj	78.15
Butter	10 g	304kj	15.50

Step 2: Calculate total sweetness of diet

= Amount consumed*sweetness value
= Apple (120*35.33) + Bread (60*40.00) + Honey (15*78.15) + Butter (10*15.50)
= 4239.6 + 2400.0 + 1172.2 + 155.0
= 7966.8

Step 3: Calculate sweet density of diet (per 1000kj)

= Total sweetness/total kilojoules consumed*1000
= 7966.8/1352*1000
= 5892.6

The total sweetness of the diet is 7966.8 and the sweet density is 5892.6.
Step 4: Repeat for saltiness and fatty mouthfeel
Descriptive data of the sensory profile and sensory density of diets by individual characteristics are presented in Table 1, but not discussed in detail as they were primarily used to help build multivariate models (see below). To examine the relationships between the nutrient and sensory aspects of the diet, Pearson's correlations were used. A correlation greater than 0.5 was considered strong, between 0.3 and 0.5 moderate, and less than 0.3 weak (Cohen, 1988). In order to explore the relative relationships between food groups, sensory impact, composition (fat, sugar, salt) and energy, ratios of percentage contributions were calculated, with higher ratios indicating greater impact of sensation to composition (see worked example below).

Step 1. Sample of simplified dietary from one individual for one day of intake and sensory data for sweetness, expressed as a percentage of daily total.

	Percentage of daily total		
Example food groups	Sweetness	Sugar	Energy
Fruit	17.3	22.2	5.9
Vegetables	9.5	4.9	6.6
Grains	9.3	7.6	23.4
…repeat for all food groups			

Step 2: Calculate ratios for percentage sweetness to percentage nutrient composition and percentage sweetness to percentage energy.

Sweet:sensory ratio for fruit = % sweetness from fruit / percentage sugar from fruit
= 18.6 / 22.2
= 0.84

Sweet:energy ratio for fruit = % sweeteness from fruit / percentage energy from fruit
= 17.3 / 5.9
= 2.93

Individual characteristics' group data (Table 1) were initially subjected to univariate analysis (ANOVAs, data not shown) and Pearson correlations (Table 2) to determine relationships for building multivariate models. Linear regression models were used to determine whether the sensory properties (sweet, salty and fatty and interactions, fatty-sweet and fatty-salty) of the diet predicted total energy intake for adults and children. In these analyses the sensory scores (sweet, salty, fatty-mouthfeel) were used and each model was adjusted for demographic variables and BMI. Outliers were identified as those 3.5 standard deviations above or below the mean and excluded from the regression analysis. Outliers were excluded to ensure that regression results are representative of the bulk of the data. Furthermore graphical assessment revealed extreme outliers in both the dependent (energy intake) and independent (predictor) variables. Outlier elimination was possible for this analysis given the large sample size, rather than investigating each outlier individually.

Statistical significance is considered to be $p < 0.05$. Descriptive and food group analysis was conducted in IBM SPSS Statistics 23 (IBM Corp, 2015) and the linear regression analysis conducted using R (R Development Core Team. R).

3. Results

3.1. Objective 1: Sensory properties of diets as a predictor of energy intake in adults and children

To examine the relationships between the sensory properties of diet and energy and nutrient contents, Pearson's correlations were used. Total fatty mouthfeel, sweet and salty scores were significantly and positively correlated with total energy intake in adults and children (Table 2). The strongest correlations in adults were observed between

Table 1

Energy intake sensory scores and sensory density by demographic characteristics for adults (n = 9435) and children (n = 2718).

			Total intake								Sensory Density (intake/1000 kJ)					
			Energy intake		Sweet		Salty		Fatty		Sweet		Saltiness		Fatty	
			Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Adults	Total	Total (n = 9435)	8675	3683	46115	29999	24388	12346	27878	13679	5500	3200	3000	1500	3300	1100
	Gender	Male (n = 4329)	9957	3920	52522	34349	27268	13457	31244	14847	5400	3100	2900	1300	3200	1100
		Female (n = 5106)	7428	2942	39878	23424	21585	10421	24601	11528	5700	3300	3100	1700	3400	1200
	Age categories	18-30 (n = 1686)	9426	4078	55908	33925	28225	13698	31693	16224	6300	3500	3200	1400	3400	1200
		31-50 (n = 3565)	8872	3738	47400	30255	25338	12224	28683	13438	5600	3300	3000	1300	3300	1100
		51-70 (n = 2906)	8290	3351	40227	26144	22110	10962	25390	11472	5100	3000	2800	1300	3200	1100
		71+ (n = 1278)	7295	2752	34807	19970	18340	8963	22933	10276	4900	2400	2700	2500	3200	1300
	Weight status[a]	Underweight (n = 121)	9135	4544	52987	33813	26291	14429	30568	17936	6100	3200	3000	1300	3400	900
		Normal (n = 2736)	9032	3791	46724	29511	25258	12974	29034	14215	5400	2900	2900	1300	3300	1100
		Overweight (n = 2898)	9004	3545	46063	28934	24943	12169	28377	13044	5300	2800	2900	1200	3200	1000
		Obese (n = 2203)	8321	3545	47678	31728	23553	11528	26940	13043	6000	3900	3000	1500	3400	1200
Children	Total	Total (n = 2718)	7941	3192	48160	27919	20532	10307	27151	13348	6200	2900	2600	1000	3500	1100
	Gender	Males (n = 1373)	7653	2840	46021	32039	18568	8197	25274	11098	6200	2700	2600	900	3500	1100
		Females (n = 1345)	8153	3239	48132	26434	20877	10381	28016	13715	6200	3100	2600	1000	3400	1100
	Weight status[a]	Underweight (n = 118)	7826	3189	53014	34625	21272	10955	26418	12923	6000	2400	2400	700	3400	1000
		Normal (n = 1537)	7570	3024	46176	20402	21076	11567	26983	13947	6000	2600	2600	900	3500	1100
		Overweight (n = 412)	7506	3159	44779	26229	18761	9177	25392	12617	6800	4100	2800	1000	3400	1200
		Obese (n = 153)	8128	2181	48625	23728	23650	9503	27505	11668	6400	2300	2800	1000	3600	1200

[a] Individuals without a measurement for calculating weight status are not presented in this table.

energy and fatty mouthfeel (0.740, $p < 0.01$), meaning individuals who consumed more energy also tended to have diets that were higher in fatty mouthfeel. The correlation between sensory saltiness of the diet and energy was 0.623 ($p < 0.01$) in adults and between sweetness of the diet and energy was 0.517 ($p < 0.01$). Similar correlations were observed for children (Table 2).

After controlling for age, sex and BMI (on the basis of the univariate analyses), the total sweetness, saltiness and fatty mouthfeel of adults' diets were all significant predictors of total energy intake, and the model accounted for 56% of the variance in energy intake (Adjusted R square = 0.561). Total fatty mouthfeel was the strongest positive predictor of total energy intake ($\beta = 0.492$, $p < 0.01$). Saltiness ($\beta = 0.16$, $p < 0.01$) and sweetness ($\beta = 0.138$, $p < 0.01$) of the diet were also positive significant predictors of energy intake, but standardised beta weights were smaller than for fatty mouthfeel (Table 3). Similar results were observed for children. However, age and BMI were also significant predictors of energy intake. This model accounted for 67% of the variance in energy intake in children (Table 3). Interactions (sweet-fatty and salty-fatty) did not contribute to the models and were deleted.

3.2. *Objective 2: Understanding the contribution of food groups to total energy and sensory profiles of the diet*

Table 4 shows the percentage contribution of food groups to the total energy, nutrient and sensory profiles of the diet. Discretionary foods were the highest food group contributor to total energy (32.2%), as well as sweetness (43.9%) and sugar (34.7%) intake in adults. Also contributing to the sweetness (and sugar) of the diet were fruit (contributing 19.6% to sugar and 17.6% to sweetness) and dairy foods (16.2% to sugar and 14.6% to sweetness). Food groups which contributed most to saltiness and sodium of adults' diets were discretionary foods (31.9% and 25.0% respectively), grains (26.1% and 19.0% respectively) and meat and alternatives (18.8% and 17.2% respectively). Discretionary foods also contributed most to total fat intake (32.7%), followed by similar proportions from dairy and grains, whereas dairy foods (23.4%) and discretionary foods (23.0%) contributed most to the fatty mouthfeel of diets. Grains and meat were also important

Table 2

Pearson correlation coefficients between energy and nutrient intake and unadjusted sensory scores (sweetness, saltiness, fatty mouthfeel) for adults (n = 9435) and children (n = 2718).

		Nutrient intake				Sensory intake		
		Energy (kj)	Fat (g)	Sugar (g)	Sodium (mg)	Fatty	Sweet	Salty
Adults	Energy	1	.841**	.628**	.619**	.740**	.517**	.623**
	Fat	.841**	1	.417**	.578**	.659**	.350**	.545**
	Sugars[a]	.628**	.417**	1	.303**	.518**	.750**	.344**
	Sodium	.619**	.578**	.303**	1	.554**	.337**	.696**
Children	Energy	1	.896**	.713**	.718**	.760**	.635**	.749**
	Fat	.896**	1	.509**	.681**	.690**	.459**	.673**
	Sugars	.713**	.509**	1	.381**	.540**	.834**	.424**
	Sodium	.718**	.681**	.381**	1	.554**	.431**	.757**

**Correlation is significant at the 0.01 level (2-tailed).

Kj: kilojoules, g: grams; mg: milligrams.

[a] Total sugars is the sum of added and free sugars in the diet.

Table 3
Predicting energy intake (kJ) using sensory score for adults (n = 7716) and children (n = 2715).

		Unstandardised B	Standard Error	Standardised β	Significance P <	% variance	Adjusted R Square
Adults	Age	5.340	1.500	0.028	0.001	2	0.561
	Sex	−1080.000	51.200	−0.164	0.001	10	
	Weight Status (BMI)	−35.900	4.720	−0.059	0.001	0.4	
	Sweetness Intake	0.018	0.001	0.138	0.001	1.4	
	Salty Intake	0.050	0.003	0.161	0.001	1.6	
	Fatty Intake	0.136	0.003	0.492	0.001	41	
Children	Age	87.544	9.910	0.143	0.001	12	0.667
	Sex	−340.069	74.300	−0.058	0.001	3.6	
	Weight Status (BMI)	−66.858	10.800	−0.093	0.001	1.9	
	Sweetness Intake	0.029	0.002	0.240	0.001	4	
	Salty Intake	0.085	0.006	0.278	0.001	4.5	
	Fatty Intake	0.092	0.004	0.382	0.001	41	

Table 4
Percentage contribution of food groups to total dietary nutrient intake and total dietary sensory profile, for adults (n = 9435) and children (n = 2718).

	Nutrient intake	Energy		Fat		Sugars[a]		Sodium	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
Adults	Fruit	5.6	7.1	0.8	3.0	19.6	21.6	0.3	1.0
	Vegetables	7.2	9.8	7.1	12.6	6.4	10.0	9.5	16.8
	Grains	23.6	16.9	13.1	16.0	8.8	10.9	26.1	20.5
	Meat	17.9	16.6	24.9	23.4	3.4	7.8	18.8	21.8
	Dairy	9.5	9.4	12.9	14.3	16.2	17.0	9.5	10.8
	Discretionary	32.2	20.9	32.7	25.1	43.9	28.2	31.9	24.5
	Healthy fats	2.9	5.8	7.6	13.2	0.4	1.5	1.0	2.7
	Other	1.1	4.1	0.9	3.0	1.2	5.9	2.8	5.7
	Sensory intake			**Fatty mouthfeel**		**Sweetness**		**Salty**	
				Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**
	Fruit			1.6	3.0	17.6	19.4	1.3	3.0
	Vegetables			8.0	12.4	9.9	12.9	11.3	17.5
	Grains			14.5	17.5	8.6	11.0	19.0	18.7
	Meat			18.5	18.4	6.9	11.1	17.2	18.9
	Dairy			23.4	19.2	14.6	16.1	6.7	8.2
	Discretionary			23.0	20.1	34.7	27.8	25.0	21.4
	Healthy fats			1.8	3.7	0.4	1.1	1.0	2.4
	Other			9.1	9.8	7.3	9.7	18.5	14.4
Children	**Nutrient intake**	**Energy**		**Fat**		**Sugar**		**Sodium**	
		Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
	Fruit	6.7	6.6	0.6	1.1	21.8	19.8	0.4	0.8
	Vegetables	4.0	6.8	3.7	8.1	2.7	5.0	4.3	10.6
	Grains	24.6	15.2	12.4	14.6	7.3	8.8	29.2	19.2
	Meat	13.4	14.4	18.0	19.5	2.3	5.4	14.9	19.5
	Dairy	12.7	11.2	17.5	16.2	18.1	17.8	11.0	11.2
	Discretionary	36.7	20.3	43.0	24.8	47.3	26.1	38.0	24.1
	Healthy fats	1.6	3.4	4.7	8.8	0.1	0.6	0.9	2.2
	Other	0.2	2.5	0.2	2.8	0.4	3.8	1.5	2.7
	Sensory intake			**Fatty mouthfeel**		**Sweetness**		**Salty**	
				Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**
	Fruit			1.8	2.8	21.5	19.6	1.8	3.0
	Vegetables			3.9	7.8	4.7	7.5	5.9	12.0
	Grains			15.7	17.3	7.6	9.1	22.1	19.1
	Meat			13.5	16.1	4.6	8.1	14.1	17.1
	Dairy			30.6	22.7	18.9	18.7	10.1	10.0
	Discretionary			27.5	20.7	38.6	26.0	32.0	21.8
	Healthy fats			1.2	2.6	0.2	0.5	0.8	1.9
	Other			5.7	6.5	3.9	5.7	13.2	10.5

---

[a] Total sugars is the sum of added and free sugars in the diet.

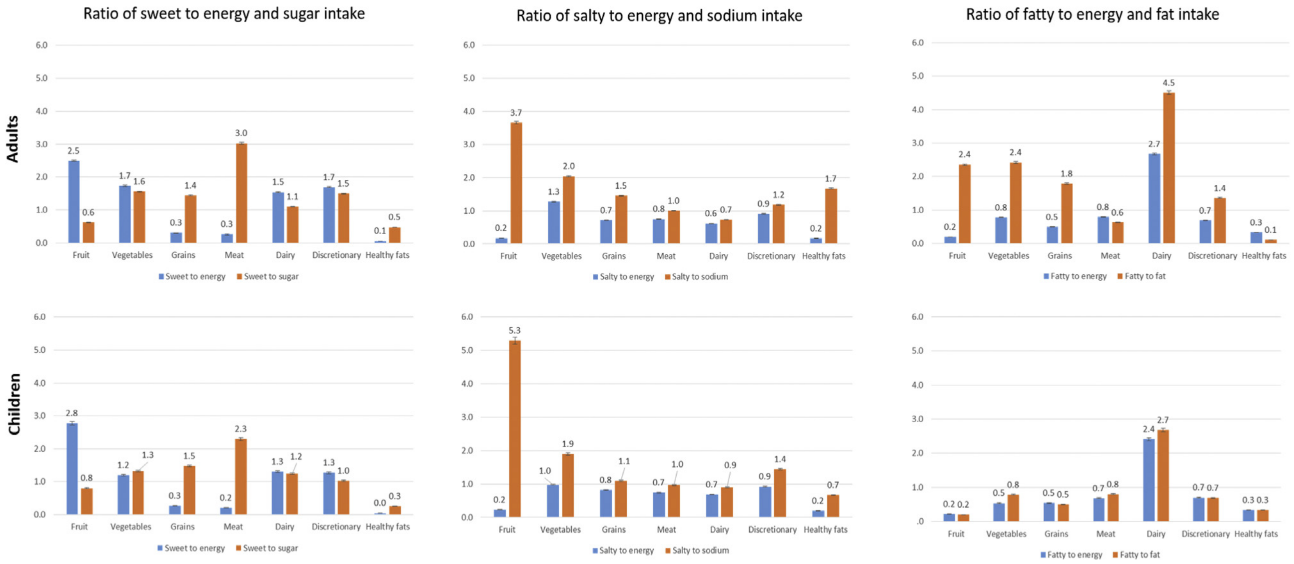


Fig. 1. Ratios of mean (standard error of the mean) sensory to energy and sensory to nutrient composition of diets.[1]
[1] Higher ratio equates to higher sensory impact of food group to the diet.

contributors to total fat intake and the fatty mouthfeel of the diet. The pattern was similar for children with one exception, saltiness from ‘other’ foods (a miscellaneous category including condiments) was greater for adults than for children who derived more saltiness (but not sodium) from meat.

To determine the contribution of food groups to “sensory sensation” and the relationship between sensory and nutrient composition and energy intake, ratios were calculated. For sweetness, fruit has a higher sweetness to energy ratio but a 5-fold lower sweetness to sugar ratio (Fig. 1). This pattern is reversed for grains and meat where the sweetness to sugar ratios are much higher than the sweetness to energy ratios. Almost all food groups had a lower saltiness to energy ratio (ratios < 1), but higher saltiness for salt ratio. In terms of fatty mouthfeel, dairy foods had the highest fatty mouthfeel to fat ratios in adults' diets and, for both children and adults in general, dairy foods provided the highest ratio of fatty mouthfeel to both energy and fat, i.e. the greatest sensation for composition.

Comparing the sensory sensation of adults and children's diets, the relative contributions of many foods groups were similar between adults and children, and particularly for sweet sensation. For saltiness, children's diets had higher saltiness to salt ratios for fruit, discretionary and dairy foods than adults, whereas adults' diets had higher saltiness to salt ratios for grains. Adults' diets had a higher fatty mouthfeel to fat ratio than children particularly across important food groups like discretionary foods, grains, fruit and vegetables.

4. Discussion

The first objective of this analysis was to explore how different sensory characteristics of the diet contribute to total daily energy intake. Using data from a nationally representative sample of Australian adults and children, fatty mouthfeel, saltiness and sweetness of diets were found to be moderately to strongly correlated with their corresponding nutrients and energy intake. Most importantly, multivariate analysis suggested that fatty mouthfeel was the strongest predictor of total energy intake and, whilst both saltiness and sweetness make contributions, these were smaller in comparison to fatty mouthfeel. The importance of fatty mouthfeel is consistent with the energy density of fat relative to other macro-nutrients. The strength of the correlations in this study are stronger than other international data examining the relationship between sweetness and energy intake from processed foods alone, as opposed to whole diet (van Langeveld et al., 2017).

There is evidence that the interactions between sweetness and fatty mouthfeel, and saltiness and fatty mouthfeel may be important (Bolhuis, Costanzo, Newman, & Keast, 2015; Drewnowski & Schwartz, 1990; Emmett & Heaton, 1995) but neither contributed to the variance explained in the multivariate regression models, hence were omitted from the final models presented here. These results suggest that sweetness or saltiness *per se* only make small contributions to the relationship to EI, and there is no evidence that sweetness or saltiness in combination with fat, are associated with energy intake at a population level but rather that fattiness is the major contributor to total energy intake. This supports findings of a French longitudinal study whereby liking for fat (compared to basic tastes) has been shown to be a risk factor for obesity (Lampuré et al., 2016). However, in other Australian data examining the sensory profile associated with dietary patterns of varying diet quality, there was no relationship with fatty mouthfeel, meaning dietary patterns that were considered to be healthier were not associated with lower fatty mouthfeel (Cox et al., 2018). However, the outcome of overall diet quality in this context was operationalised as compliance with the Australian Dietary Guidelines, and while they recommend appropriate amounts of food are consumed to maintain energy balance, the outcome was not energy intake *per se*.

The second objective was an analysis of the ratios of dietary composition (sugar, sodium, and fat) to sensory impact (sweet, salty, fatty mouthfeel) across food groups identifying where most sensory stimulation from content can be achieved. These ratios may also reveal where high composition has lesser impact on perception, notably amongst discretionary foods. Discretionary foods are the highest contributor to nutrients, namely sugar, sodium and fat, as well as the sensory modalities studied here, in both adults and children. This is not surprising given this single food group contributes 35–40% of total energy in Australian's diets (Rangan, Randall, Hector, Gill, & Webb, 2008, 2009). Core foods can provide similar sensory stimulation to discretionary foods (Fig. 1) relative to their nutrient or energy content, with some notable exceptions of fatty mouthfeel and fat (i.e. meats have lower ratios), suggesting sensory stimulation could be satisfied by switching to core foods. Meat and grains provide considerable sodium without providing proportional sensory impacts of saltiness. The hedonics, essential functionality but poor regulation of sodium have been described before (Geerling & Loewy, 2008; Morris, Na, & Johnson, 2008) and our data augment this knowledge by showing that, at a dietary level, poor regulation is further compromised by poor sensory detection. It has been suggested processing tends to break the sensory detection of nutrient composition (van Dongen et al., 2012) but in terms of dietary food categories, as defined by healthy eating recommendations, discretionary foods provide sensory qualities that should enable similar detection to core (minimally or non-processed) foods (Fig. 1); however, there is poor detection of fat (low fatty mouthfeel to fat ratio) amongst discretionary foods relative to other food groups with the notable exception of meats.

Interestingly children's reported diets have lower fatty sensation to fat ratios than adults across most food groups (Fig. 1) possibly reflecting low fat reporting by adults.

Dairy foods as a single food group were a key source of fat in the diet and fatty mouthfeel, but the high ratio of fatty mouthfeel to fat and energy is interesting. Dairy foods provide a relatively small amount of fat relative to the sensory stimulation they provide, perhaps related to the mouth-coating effect of dairy liquids and semi-solids (e.g. yoghurts and creams) (Akhtar, Stenzel, Murray, & Dickinson, 2005; Van Aken, Vingerhoeds, & De Wijk, 2011) that are considered highly palatable (Drewnowski & Greenwood, 1983). Given the nutritional value of dairy foods and their palatability, this observation may be useful in informing public health messages to suggest that if consumers seek the pleasure of fatty mouthfeel they could satisfy this with a small amount of dairy foods (further assisted by gums and thickeners (Maier, Anderson, Karl, Magnuson, & Whistler, 1993)) and warrants future testing. By examining the nutrient/sensory profiles of diets in this novel way, there would appear to be opportunities to encourage sensory stimulation from core foods, such as dairy foods for fattiness or fruit for sweetness (Fig. 1), rather than discretionary foods – which provide relatively low sensory stimulation for their nutrient content.

Analysis of the ratios of composition to sensory impact by food group suggests that care is required when using the senses to attempt to detect food composition and energy intake. For example, much of the fat in meat and discretionary foods appears to be ‘hidden’ (low sensory impact to content ratio); however, discretionary foods still provide the greatest proportion of dietary energy with fattiness as the largest predictor energy intake. Fat in dairy products appears to provide a recognizable fatty mouthfeel (a ratio almost twice the nutrient content) and more than twice the ratio to energy content. The perception of fatty mouthfeel may explain why dairy avoidance is reported by some population segments as a tactic for controlling fat intake and body weight, despite some evidence that dairy foods are not associated with adiposity (Phillips et al., 2003).

The strengths of this study include the use of a trained sensory panel to estimate the sensory characteristics of over 720 foods, a method considered to be the gold standard in sensory science (Meilgaard et al., 2007b). In addition, we applied these data to a large, nationally representative sample of the Australian population who had completed 24-h recalls to assess their dietary intake. While 24-h recall is considered to be a robust and valid method of measuring dietary intake in population surveys, like all measures of intake they can be subject to misreporting. It has been estimated that Australian adults may misreport their energy intake by up to 20%, and misreporting may be greater in obese individuals (Cox et al., 2018), which may have influenced these results. Further, these data represent one day of intake and may not represent individuals' usual dietary patterns. A final limitation of this study was its cross sectional design which limits any inference of causal relationships.

5. Conclusions

In this study examining the sensory profile of diets of Australian adults and children, fattiness of the diet was the largest sensory contributor to dietary energy intake, followed by sweetness and saltiness. Furthermore ratios of nutrients and energy intake to sensory by food group revealed where the greatest sensory impact can be achieved for the minimum amount of energy or nutrient content, for example, fat in meats and discretionary foods has a low sensory impact whereas fat in dairy products has a high impact. Given that there is evidence that sweetness, saltiness and fattiness remain rewarding characteristics of foods, the results of this study suggest that choosing particular foods for their sensory value, such as the fatty mouthfeel provided by dairy foods, may achieve sensory satisfaction without the energy-density, such as when fatty mouthfeel is achieved by consuming excessive discretionary foods. Increasing consumers' awareness of the sensory properties and sensory satiation of foods may be an additional message to promote alongside current nutritional benefits of healthy foods and dietary patterns. Similarly these data can be used to help formulate new food products with greater sensory detection (and possible pleasure) for nutrient and energy content.

Author contributions

D.N.C and G.A.H conceived the idea and designed the study; H.J.L prepared the sensory database; G.A.H, M.A.R and M.B. conducted the statistical analysis and wrote the results; D.N.C and G.A.H wrote the initial draft of the manuscript; and all authors contributed to the final review of the manuscript.

Conflicts of interest

The authors declare no conflict of interest. The funding sponsors had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, and in the decision to publish the results. The manuscript was sent to the founding sponsors following submission.

Acknowledgments

The study was funded by the Australian Sugar Industry Alliance. We thank colleagues Dr Astrid Poelman and Jess Heffernan for undertaking sensory profiling of the foods.

Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.appet.2018.08.039.

References

Akhtar, M., Stenzel, J., Murray, B., & Dickinson, E. (2005). Factors affecting the perception of creaminess of oil-in-water emulsions. *Food Hydrocolloids, 19*, 521–526.

Australian Bureau of Statistics (2011-13). *Australian health survey: Users' guide.* http://www.abs.gov.au/ausstats/abs@.nsf/mf/4363.0.55.001.

Bolhuis, D. P., Costanzo, A., Newman, L. P., & Keast, R. S. (2015). Salt promotes passive overconsumption of dietary fat in humans–3. *Journal of Nutrition, 146*, 838–845.

Bolhuis, D. P., Lakemond, C., de Wijk, R., Luning, P., & 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.

Bolhuis, D. P., Lakemond, C., de Wijk, R., Luning, P., & de Graaf, C. (2012). Effect of salt intensity in soup on ad libitum intake and on subsequent food choice. *Appetite, 58*, 48–55.

Cohen, J. (1988). Set correlation and contingency tables. *Applied Psychological Measurement, 12*, 425–434.

Cox, D. N., Carty, D. J., Hendrie, G. A., Poelman, A. M., Krishnamurthy, R., Lease, H. J., et al. (2013). *Sensory characteristics of children's reported diets and implications for nutrient and weight status 10th Pangborn Symposium.* Rio de Janeiro: Rio de Janeiro.

Cox, D. N., Hendrie, G. A., & Carty, D. (2016). Sensitivity, hedonics and preferences for basic tastes and fat amongst adults and children of differing weight status: A comprehensive review. *Food Quality and Preference, 48*, 359–367.

Cox, D. N., Hendrie, G. A., & Lease, H. J. (2018). Do healthy diets differ in their sensory characteristics? *Food Quality and Preference, 68*, 12–18.

van Dongen, M. V., van den Berg, M. C., Vink, N., Kok, F. J., & de Graaf, C. (2012). Taste–nutrient relationships in commonly consumed foods. *British Journal of Nutrition, 108*, 140–147.

Drewnowski, A. (1998). Energy density, palatability, and satiety: Implications for weight control. *Nutrition Reviews, 56*, 347–353.

Drewnowski, A., & Greenwood, M. (1983). Cream and sugar: Human preferences for high-fat foods. *Physiology & Behavior, 30*, 629–633.

Drewnowski, A., & Schwartz, M. (1990). Invisible fats: Sensory assessment of sugar/fat mixtures. *Appetite, 14*, 203–217.

Emmett, P., & Heaton, K. (1995). Is extrinsic sugar a vehicle for dietary fat? *The Lancet, 345*, 1537–1540.

Geerling, J., & Loewy, A. (2008). Central regulation of sodium appetite. *Experimental Physiology, 93*, 177–209.

Grabenhorst, F., Rolls, E. T., Parris, B. A., & d'Souza, A. A. (2009). How the brain represents the reward value of fat in the mouth. *Cerebral Cortex, 20*, 1082–1091.

Hayes, J. E., Sullivan, B. S., & Duffy, V. B. (2010). Explaining variability in sodium intake through oral sensory phenotype, salt sensation and liking. *Physiology & Behavior, 100*, 369–380.

IBM Corp (2015). *Spss statistics for windows, version 23.0.* Armonk, NY: IBM Corp.

Lampuré, A., Castetbon, K., Deglaire, A., Schlich, P., Péneau, S., Hercberg, S., et al. (2016). Associations between liking for fat, sweet or salt and obesity risk in French adults: A prospective cohort study. *International Journal of Behavioral Nutrition and Physical Activity, 13*, 74.

van Langeveld, A. W., Gibbons, S., Koelliker, Y., Civille, G. V., de Vries, J. H., de Graaf, C., et al. (2017). The relationship between taste and nutrient content in commercially available foods from the United States. *Food Quality and Preference, 57*, 1–7.

Lease, H., Hendrie, G. A., Poelman, A. A., Delahunty, C., & Cox, D. N. (2016). A sensory-diet database: A tool to characterise the sensory qualities of diets. *Food Quality and Preference, 49*, 20–32.

Low, Y. Q., Lacy, K., & Keast, R. (2014). The role of sweet taste in satiation and satiety. *Nutrients, 6*, 3431–3450.

Maier, H., Anderson, M., Karl, C., Magnuson, K., & Whistler, R. (1993). *Guar, locust bean, tara, and fenugreek gums* (3rd ed.). Elsevier Publishing.

Martin, C., Visalli, M., Lange, C., Schlich, P., & Issanchou, S. (2014). Creation of a food taste database using an in-home "taste" profile method. *Food Quality and Preference, 36*, 70–80.

Mattes, R. D. (1997). The taste for salt in humans. *American Journal of Clinical Nutrition, 65*, 692S–697S.

Meilgaard, M., Civille, G., & Carr, B. (2007a). Overall difference tests: Does a sensory difference exist between samples. *Sensory Evaluation Techniques, 4*, 63–104.

Meilgaard, M., Civille, G. V., & Carr, B. (2007b). *Sensory evaluation techniques* (4th ed.). New York, NY: CRC Press.

Mennella, J. A. (2014). Ontogeny of taste preferences: Basic biology and implications for health. *American Journal of Clinical Nutrition, 99*, 704S–711S.

Morris, M., Na, E., & Johnson, A. (2008). Salt craving: The psychobiology of pathogenic sodium intake. *Physiology & Behavior, 94*, 709–721.

National Health and Medical Research Council. Australian guide to healthy eating. https://www.eatforhealth.gov.au/guidelines/australian-guide-healthy-eating.

National Health and Medical Research Council (2013). *Australian dietary guidelines.* Canberra: National Health and Medical Research Council.

Peciña, S., Smith, K. S., & Berridge, K. C. (2006). Hedonic hot spots in the brain. *The Neuroscientist, 12*, 500–511.

Pey, S., Van Langeveld, A. W., Pol, K., Siebelink, E., de Graaf, C., & Yan, S. (2018). Similar taste-nutrient relationships in commonly consumed Dutch and malaysian foods. *Appetite, 125*, 32–41.

Phillips, S., Bandini, L., Cyr, H., Colclough-Douglas, S., Naumova, E., & Must, A. (2003). Dairy food consumption and body weight and fatness studied longitudinally over the adolescent period. *International Journal of Obesity, 27*, 1106–1113.

R Development Core Team R: A language and environment for statistical computing. http://www.R-project.org.

Rangan, A. M., Randall, D., Hector, D. J., Gill, T. P., & Webb, K. L. (2008). Consumption of 'extra'foods by australian children: Types, quantities and contribution to energy and nutrient intakes. *European Journal of Clinical Nutrition, 62*, 356–364.

Rangan, A., Schindeler, S., Hector, D., Gill, T., & Webb, K. (2009). Consumption of 'extra'foods by australian adults: Types, quantities and contribution to energy and nutrient intakes. *European Journal of Clinical Nutrition, 63*, 865–871.

Sobal, J., Bisogni, C., Devine, C., & Jastran, M. (2006). A conceptual model for the food choice process over the life course. In R. Shepherd, & M. Raats (Eds.). *The psychology of food choice* (pp. 1–18). Cambridge, MA: CABI Publishing.

Steiner, J. E. (1979). Human facial expressions in response to taste and smell stimulation. *Advances in Child Development and Behavior, 13*, 257–295.

Urbano, C., Deglaire, A., Cartier-Lange, E., Herbreteau, V., Cordelle, S., & Schlich, P. (2016). Development of a sensory tool to assess overall liking for the fatty, salty and sweet sensations. *Food Quality and Preference, 48*, 23–32.

Van Aken, G., Vingerhoeds, M., & De Wijk, R. (2011). Textural perception of liquid emulsions: Role of oil content, oil viscosity and emulsion viscosity. *Food Hydrocolloids, 25*, 789–796.

Yuan, W. L., Lange, C., Schwartz, C., Martin, C., Chabanet, C., de Lauzon-Guillain, B., et al. (2016). Infant dietary exposures to sweetness and fattiness increase during the first year of life and are associated with feeding practices. *Journal of Nutrition, 146*, 2334–2342.