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Research report

Eating rate of commonly consumed foods promotes food and energy intake☆

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ABSTRACT

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

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Introduction

In last decades, food availability has shifted from natural, minimally processed foods to highly processed, ready-to-eat foods, characterized by an increase in energy density and a decrease in fiber content (Cordain et al., 2005; Slimani et al., 2009). In addition, consumption of energy-yielding liquids has increased (Malik, Schulze, & Hu, 2006). This shift coincides with an increased prevalence of obesity, which may imply that these events could be related. Several studies indeed indicate that energy dense, low-fiber diets, and the consumption of energy-yielding liquids are associated with obesity (Anderson et al., 2009; Bes-Rastrollo et al., 2008; Malik et al., 2006; Savage, Marini, & Birch, 2008). This suggests that ingesting these foods may potentially lead to an increased energy intake.

It has been demonstrated that dietary fiber decreases eating rate (Haber, Heaton, Murphy, & Burroughs, 1977) and that liquid foods can be ingested more rapidly than solid foods (Zijlstra, Mars, de Wijk, Westerterp-Plantenga, & de Graaf, 2008). Accordingly, eating rate may be a mediating factor that explains why ingesting low-fiber foods and energy-yielding liquids would result in an increased intake. Due to a high eating rate, the oral exposure to food, i.e. orosensory exposure, is low. Previous studies demonstrated that a low orosensory exposure is associated with a high food intake (e.g. Cecil, Francis, & Read, 1998; Cecil, Francis, & Read, 1999; French & Cecil, 2001; Zijlstra, de Wijk, Mars, Stafleu, & de Graaf, 2009). When orosensory exposure is low, few signals from the oral cavity may reach the brain, leaving insufficient time for satiety signals to induce meal termination (Rolls, 2007). This may result in a high food intake.

So far, literature on the relation between eating rate and food intake has focused on experimentally manipulated eating rates of single foods (Epstein, Parker, McCoy, & McGee, 1976; Kissileff, Zimmerli, Torres, Devlin, & Walsh, 2008; Kral, Buckley, Kissileff, & Schaffner, 2001; Laessle, Lehrke, & Duckers, 2007; Lavin, French, Ruxton, & Read, 2002). No information is yet available on eating rate of a broad range of commonly consumed foods. This information is, however, important in order to estimate the actual contributions of eating rate to total food intake, within the context of our current food environment. In addition, this will enable us to identify food properties that are related to eating rate. The objectives of this study were therefore to investigate the eating rate of commonly consumed foods, to investigate the associations with food and energy intake and the associations with energy density and macronutrient content.

Methods

Subjects

Men and women, aged 18–35 y, were recruited by a mailing list, containing subscriptions of people who are interested in participating in consumer research. Potential subjects were screened with a questionnaire to determine whether they met the following

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inclusion criteria: they had a BMI of 18.5–25 kg/m^2, were in good physical and mental health, did not smoke, were not restraint eaters (men >2.90, women >3.40 on the Restraint subscale of the Dutch Eating Behavior Questionnaire (Strien, 1986)), were not following an energy restricted diet, and were not pregnant or lactating. Subjects who had food allergies or disliked the foods that they had to test were excluded. In total, 13 men (aged 21.9 (SD 2.8) y, BMI 22.2 (SD 1.9) kg/m^2, restraint score 1.7 (SD 0.6)) and 24 women (aged 24.0 (SD 3.5) y, BMI 21.4 (SD 1.5) kg/m^2, restraint score 2.5 (SD 0.6)) participated in the study. Each subject tested a total of 7 food items, in separate test sessions. From these 7 food items, two were reference foods (whole-meal bread and yoghurt, see data analyses), which were similar for all subjects. In addition, each subject tested 5 other food items, which were randomly assigned to the subjects. The subjects were informed about the measurement of the ingestion time but they were not aware of the measurement of the ad libitum food intake. All subjects received financial compensation for their participation. The Medical Ethics Committee of Wageningen University approved the study protocol; this study was performed in accordance with the ethical standards laid down in the Declaration of Helsinki. This study is registered in the Dutch Trial Register as NTR1835.

Foods

The food items used in this study were selected to represent a range of commonly consumed foods within the Netherlands, using the National Food Consumption Survey, 2003 (Hulshof et al., 2003). This survey contains several food groups and from each relevant food group (fats and oils, alcoholic drinks, and herbs, spices and sauces were not considered), we selected those foods that were often consumed (Hulshof et al., 2003). We were careful to select foods that were normally consumed at breakfast, lunch, dinner, and between meals. The foods represented a range of natural and processed foods, covering a wide range of nutritional, textural and hedonic characteristics. Table 1 provides an overview of the foods used and their macronutrient composition (NEVO-tabel).

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

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

Food item	Tested by subjects (*N*)	Serving size[b] (g)	Energy density (kJ/100 g)	Fat (g/100 g)	Carbohydrates (g/100 g)	Protein (g/100 g)	Fiber (g/100g)
Boiled potatoes	3	600	325	0	16.8	2.3	3.1
French fries	3	600	1206	8.8	46.0	5.8	3.2
Mashed potatoes	4	600	347	1.6	14.6	2.5	2.5
White rice	4	600	623	0.4	32.7	3.1	0.5
Brown rice	3	600	505	1.4	23.6	3.1	1.4
Boiled carrots	5	500	77	0	4.0	0.5	1.8
Peas	5	500	360	1.0	14.0	5.0	4.7
Cucumber	5	500	34	0	1.2	0.8	0.7
Tomato	3	500	48	0	1.9	0.9	1.3
Carrots raw	3	500	48	0	2.2	0.6	3.0
Lettuce	4	300	36	0	1.2	0.9	0.8
Apple	4	500	207	0	11.8	0.4	2.3
Banana	6	500	375	0.2	20.4	1.2	2.7
Pineapple	3	500	211	0	12.0	0.4	1.2
Meatball	4	400	1127	17.4	8.0	20.5	0
Chicken breast	5	400	667	3.8	0	30.9	0
Boiled egg	3	400	615	10.6	0	13.1	0
Smoked salmon	4	300	838	11.2	0	25.0	0
Tomato soup	5	1000	220	1.0	8.0	2.0	0.7
Vegetable soup	4	1000	90	0.7	2.5	1.5	1.0
White bread	4	400	1101	2.1	52.0	8.1	2.7
Whole-meal bread	37	400	1013	2.3	45.1	9.5	5.1
Rice waffle	3	150	1590	2.1	81.7	7.2	4.1
Cracker	3	200	1955	17.0	70.0	8.0	2.2
Potato chips light	6	200	1945	23.1	57.3	6.9	4.7
Chocolate	5	350	2247	32.6	54.7	6.6	0.8
Liquorice	3	350	1479	0	77.0	10.0	0
Caramel toffee	4	350	1872	17.0	71.0	2.1	0
Spiced ginger biscuits	5	500	2052	21.3	68.3	6.1	1.5
Waffle ‘stroopwafel’	3	500	1787	16.0	66.5	3.7	0.4
Gingerbread	4	500	1295	1.2	70.2	3.4	2.5
Cake	5	500	1762	23.9	44.8	6.9	0.6
Cheese	3	300	1561	31.2	0	24.0	0
Peanuts	4	300	2592	52.1	11.0	28.1	7.7
Tea	3	1400	0	0	0	0	0
Milk	5	1400	199	1.5	4.8	3.6	0
Chocolate milk	6	1400	376	3.0	12.2	3.5	0.5
Yoghurt drink	4	1400	128	0	4.5	3.0	1.0
Apple juice	3	1400	141	0	8.2	0.1	0
Diet coke	4	1400	2	0	0.1	0	0
Fruit and fiber juice	5	1400	239	0	13.6	0.5	2
Yoghurt	37	1000	204	1.5	4.5	4.2	0
Vanilla custard	5	1000	393	2.7	14.4	2.8	0
Pureed apple	4	1000	287	0	16.6	0.3	1.4
Ice cream	4	600	910	11.4	25.7	3.0	0.3

[a] Based on the Dutch Food Composition Table, 2006 (NEVO-tabel).
[b] Serving size as offered to measure ad libitum food intake.

difference of 75%, equivalent to detecting a difference between 10 and 17.5 g/min, as relevant.

We aimed to have each food item being tested by 6 subjects. However, due to some setback in recruitment, this was not feasible, resulting in an unbalanced design. Because we needed at least 3 observations per food item, the foods with fewer observations ($n = 7$) were left out of the analyses. The final sample consisted of 45 food items, which were tested by at least 3 and maximum 6 subjects, except for the two reference foods, which were tested 37 times (see Table 1).

Experimental procedure

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

A test session consisted of two parts: measuring ingestion time and measuring ad libitum food intake. In the first part, subjects received 50 g of the food. Foods were offered in standardized, ready-to-eat pieces, if necessary (liquid and semi-solid foods did not require this). Preparation of the samples was done according to a strict protocol in order to standardize the samples, including the serving temperature of warm (65 °C) and cold (7 °C) food items. Subjects had to press a start button on a computer and immediately start eating or drinking the food in its entirety. They were instructed to ingest the foods at a for them ordinary pace, except for pausing between bites or sips, which was not allowed. After the last bite or sip was swallowed, subjects had to press a stop button. Time needed to consume the 50 g, the ingestion time, was measured. In the second part of a session, subjects were offered the same food in a large, pre-weighed amount. The exact amount that was offered, was about 2 times a large portion size. As such, the offered amount differed per food (see Table 1). In a pilot study we checked whether the offered amounts were enough to ensure unrestricted consumption. Subjects were instructed to consume the item until they were comfortably full. Actual food intake was measured to the nearest 1.0 g by weighing the leftovers. Water (125 ml) was provided, which had to be drunk in its entirety throughout the second part of the session. Before and after each session, subjects rated appetite parameters on a 9-point scale, ranging from "not . . ." to "very . . .". In a separate session, but under similar test conditions, subjects rated palatability of the 7 items that they tested on a 9-point scale ranging from "not . . ." to "very . . .".

Data analyses

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

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

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

Mean eating rate in g/min was calculated based on the mean ingestion time for that food item. Total food intake (g) consisted of both the 50 g and the ad libitum food intake. Energy intake (kJ) was calculated using the Dutch Food Composition Table 2006 (NEVO-tabel). Analyses were performed using SAS version 9.1.2 (SAS Institute Inc. 2004, Cary, NC, USA). Simple and multiple regression analyses were used to test associations with PROC REG. To normalize the error distribution, dependent variables were log-transformed in the regression analyses when necessary. To estimate the contribution of each macronutrient and dietary fiber to eating rate, backward multiple regression analyses were used. P-values <0.05 were considered significant.

Because palatability and hunger have previously been shown to influence eating rate and food intake, (Bellisle, Lucas, Amrani, & Le Magnen, 1984; Bobroff & Kissileff, 1986; Yeomans, 1996), we tested whether these variables influenced the eating rate and intake data. No main effects were found of hunger on eating rate or intake. Similarly, no main effect was found of palatability on eating rate, but palatability was positively associated with food intake ($\beta = 44.7$ ($P < 0.01$) and $R^2 = 0.22$). Nevertheless, both variables were treated as covariates in the analyses. If they were significant (partial regression coefficients of $P < 0.05$), they were maintained in the final model. In the results, it is indicated where palatability and baseline hunger influenced the associations and thus where the analyses were adjusted for these variables.

Results

The eating rate (g/min) of the foods is shown in Fig. 1. Large differences in eating rate were observed, ranging from 4.2 (SD 3.7) g/min for rice waffles to 631 (SD 507) g/min for diet coke. Eating rate for solid foods ranged from 4.2 (SD 3.7) g/min for rice waffles to 128 (SD 73) g/min for boiled carrots. For semi-solid foods it ranged from 50 (SD 36) g/min for mashed potatoes to 229 (SD 247) g/min for vanilla custard. For liquid foods it ranged from 305 (SD 252) g/min for yoghurt drink to 631 (SD 507) g/min for diet coke. These data indicate that even within a group of foods with comparable characteristics, in this case viscosity, eating rates varied extensively. Another interesting observation was that soups, which can be qualified as liquid foods, were ingested at a rate (67 (SD 29) g/min for vegetable soup and 79 (SD 28) g/min for tomato soup) similar to several solid foods.

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

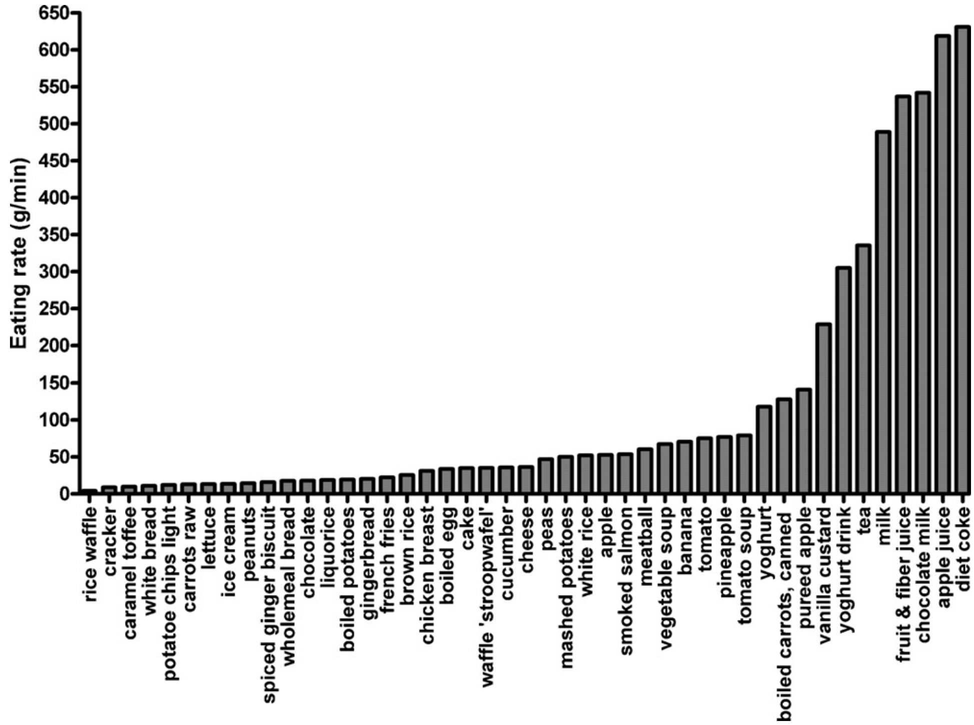

Fig. 1. Mean eating rate (g/min) of 45 food items, commonly consumed in the Netherlands.

whole-meal bread (18 (SD 21) g/min), although white bread is more processed.

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

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

To determine which food characteristics influence the eating rate of a food, we performed regression analyses using energy density, water content, macronutrient composition and fiber content. Fig. 3 shows the association between energy density (kJ/100 g) and eating rate (log g/min), with $\beta = -0.00047$ ($P < 0.01$) for energy density and $R^2 = 0.39$. After adjusting for palatability, the regression coefficient changed to $\beta = -0.00051$ ($P < 0.01$), with $R^2 = 0.50$. So when energy density of foods increases by 100 kJ/100 g, there is a 5.1% decrease in eating rate.

When investigating the association between energy density (kJ/100 g) and food intake (g), as shown in Fig. 4, we found that food intake decreased as energy density increased, with $\beta = -0.11$ ($P < 0.01$) and $R^2 = 0.29$. After adjusting for palatability and baseline hunger, the regression coefficient changed to $\beta = -0.14$ ($P < 0.01$), with $R^2 = 0.64$. However, despite of the lower food intake of energy dense foods in grams, actual energy intake (kJ) increased ($\beta = 0.90$, $P < 0.01$ and $R^2 = 0.52$), as energy density (kJ/100 g) increased

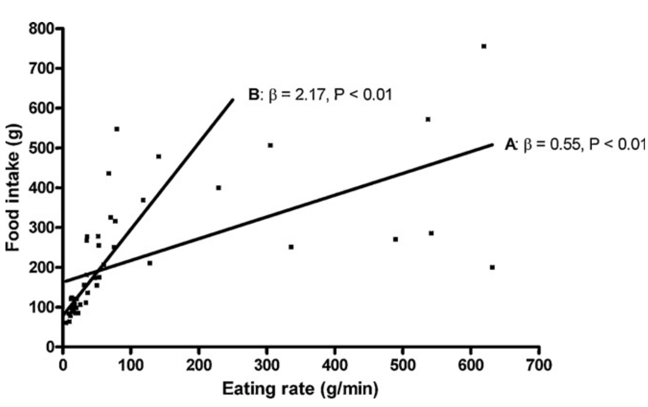

Fig. 2. The unadjusted association between eating rate (g/min) and food intake (g) for 45 food items (A) and for 33 solid foods (B). Regression analysis showed that eating rate was positively associated with food intake (A: $R^2 = 0.37$ and B: $R^2 = 0.55$).

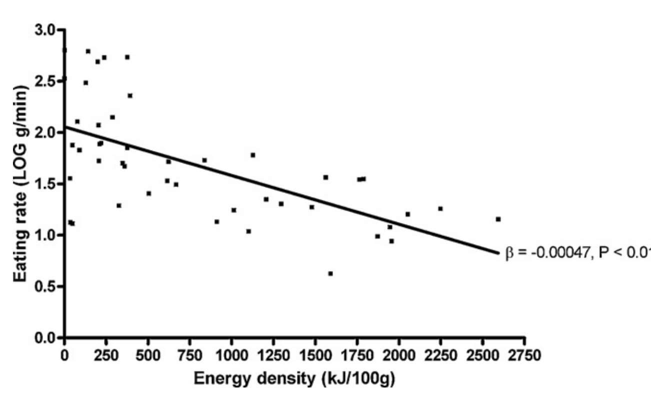

Fig. 3. The unadjusted association between energy density (kJ/100 g) and eating rate (log g/min) for 45 food items. Regression analysis showed that energy density was inversely associated with eating rate ($R^2 = 0.39$).

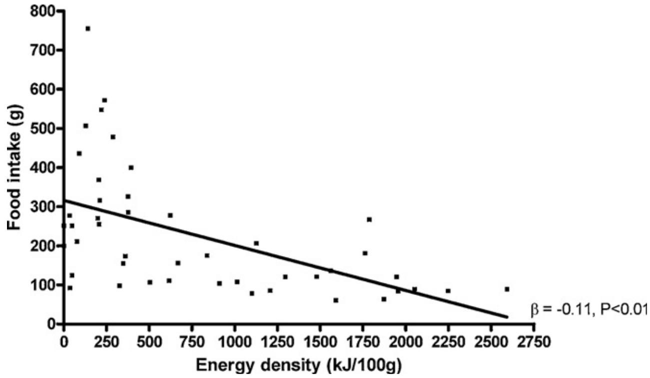

Fig. 4. The unadjusted association between energy density (kJ/100 g) and food intake (g) for 45 food items. Regression analysis showed that energy density was inversely associated with food intake ($R^2 = 0.29$).

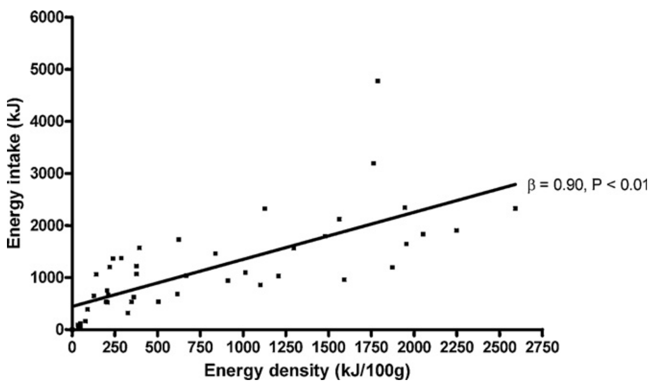

Fig. 5. The unadjusted association between energy density (kJ/100 g) and energy intake (kJ) for 45 food items. Regression analysis showed that energy density was positively associated with energy intake ($R^2 = 0.52$).

(Fig. 5). After adjusting for palatability and baseline hunger, the regression coefficient changed to $\beta = 0.82$ ($P < 0.01$), with $R^2 = 0.65$. These findings suggest that food intake is lower in energy dense foods, but this lower food intake is not sufficient to prevent a higher energy intake.

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

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

Discussion

To our knowledge, this is the first study that investigated eating rates of a range of commonly consumed foods. This study demonstrated large differences in eating rate between foods, where the food with the highest eating rate was ingested almost 160 times as fast as the food with the lowest eating rate. Even within a food category such as solid foods, eating rate between foods differed up to 30 times. In addition, this study demonstrated a positive association between the eating rate of foods and food and energy intake. This is in line with previous work (e.g. Andrade, Greene, & Melanson, 2008; Martin et al., 2007), where a lower eating rate resulted in lower food and energy intakes. In addition to this previous work, we have now demonstrated the effect across foods, rather than between subjects or within variations of a single food. Within the current food supply, there are many foods available that can be ingested rapidly. Considering the positive association that we found between eating rate and food and energy intake, consuming these foods potentially poses a risk of overconsumption.

Previously, it was demonstrated that viscosity influences food intake (Mattes & Rothacker, 2001; Zijlstra et al., 2008), such that food intake of liquid foods was higher, relative to solid or semi-solid foods, possibly because of a higher intake rate for liquids (Zijlstra et al., 2009). The differences that we observed in eating rate between foods are probably the result of differences in food properties, particularly viscosity, with major differences between liquid and solid foods. Soup is, however, an exception. The eating rate of soup, which can be qualified as a liquid, was within the range of solid foods, possibly because soup was consumed with a spoon, or because of its high temperature. Combining this finding with the finding that soup is just as satiating as solid foods (Mattes, 2005), we may suggest that eating rate is responsible for the satiating capacity of soup.

Besides viscosity, we particularly focused on the associations of eating rate with energy density, water content and macronutrient composition. We found an inverse association between energy density and eating rate and a positive association between water content and eating rate. When addressing the inverse association between energy density and eating rate, it is important to mention that, despite of a slower eating rate and a lower food intake, the energy intake of energy dense foods was higher than that of foods with a low energy density. This is consistent with the observation that daily energy intake is higher when the energy density of the foods consumed is higher (de Castro, 2004; Kral & Rolls, 2004). So increasing energy density as a means to reduce eating rate and food intake would still probably lead to an increased energy intake.

Multiple regression analyses showed that carbohydrate, protein and fiber were inversely associated with eating rate, whereas there was no association with fat. Carbohydrate content of foods can be as high as 80 g per 100 g of food. These foods have by definition a low water content. This low water content requires mastication to mix enough saliva with the food, to allow for swallowing. In addition, when foods contain complex carbohydrates, protein, or fiber, the texture of these foods is likely to be firm. A firm texture requires sufficient chewing before particles are small or soft enough to be swallowed. Fat was the only macronutrient that was not associated with eating rate, although a negative association was expected based on the observed associations of eating rate and energy density, taking into account that fat is a primary determinant of energy density (Stubbs & Whybrow, 2004). The finding that fat was not associated with eating rate suggests that fat may not have an inhibitory effect on eating rate, in contrast to the other macronutrients. This is consistent with the low satiating capacity of fat (Blundell & MacDiarmid, 1997; Doucet & Tremblay, 1997; Holt, Miller, Petocz, & Farmakalidis, 1995), where the inability of fat to "inhibit" eating rate may explain why fat is not very satiating. Fat may provide oral sensations like creaminess and softness (Drewnowski, 1995), enabling a swift passage through the oral cavity, which results in a high eating rate. So the lack of such an inhibitory effect may be caused by the effects that fat has on the texture of foods. It should be mentioned, though, that fat can also provide sensations like crunchiness, as in French fries, (Drewnowski, 1995) which may enhance oral processing and would therefore decrease eating rate. This issue clearly warrants further investigation.

It has been argued that processed foods increase eating rate (Haber et al., 1977). Some of our data indeed showed that processed foods had a faster eating rate than the same foods in an unprocessed form (e.g. boiled carrots vs. raw carrots). The relation is more complicated, however, because we also observed that white bread was ingested more slowly than the less processed whole-meal bread. In addition, some of the foods with the lowest eating rates, like caramel toffees and ice cream, were highly processed. This indicates the complexity of eating rate, where multiple food properties are involved. Besides, food properties are often related to each other. Liquid foods, for example, contain a lot of water, so evidently macronutrient content is low. And foods with a firm texture, like meat, usually contain a lot of protein. This stresses the difficulty of pointing to one single food property as a major determinant of eating rate.

There are some limitations to this study. The objective of this study was to investigate eating rate and its association with food intake, considering a large array of foods. It was not feasible for all subjects to test all 45 food items. In the current design, each subject tested seven of the 45 items. As a result, this design required adjustments for between-subject variations in eating rate. Because we could not adjust for this in the analyses, which were performed on food level, not on individual level, we used an individual calibration factor, based on the individual's eating rate of yoghurt and bread. Although this method may be arbitrary, it was nevertheless able to reduce the coefficient of variation of the ingestion time from 0.45 to 0.37. Another limitation is that we calculated a mean eating rate of 50 g of a food, not taking into account any changes in eating rate within one session. Previous research has demonstrated that during a meal, eating rate first increases and then decreases (Guss & Kissileff, 2000). The current design was necessary, however, to study the eating rates of a range of food items in a standardized way. For the same reason, subjects were instructed to consume the foods without pausing between bites. Under normal eating conditions, people may or may not pause between bites. Because we measured eating rate under such laboratory conditions, where the foods were already cut into edible portions, and were not consumed in combination with other foods, the extrapolation of our results to a normal eating situation may be limited.

The present study focused on eating rate of commonly consumed foods. We observed large differences in eating rate between foods and we found positive associations between eating rate and food and energy intake. Due to the nature of this study, we cannot draw any conclusions about causality. Nevertheless, considering the current food supply, with energy dense, low-fiber foods that can be ingested relatively quickly, the consequences of a high eating rate on daily food intake may be considerable. Cross-sectional and experimental data already suggest a link between eating rate and weight status (Hill & McCutcheon, 1984; Kral et al., 2001; Laessle et al., 2007; Llewellyn, van Jaarsveld, Boniface, Carnell, & Wardle, 2008; Otsuka et al., 2006; Sasaki, Katagiri, Tsuji, Shimoda, & Amano, 2003), which stresses the potential risk of a high eating rate on body weight gain. In this study, we did not investigate whether subjects adjusted their subsequent food intake to compensate, although an accurate compensatory response is unlikely (Caputo & Mattes, 1992; Levitsky, Obarzanek, Mrdjenovic, & Strupp, 2005; Viskaal-van Dongen, de Graaf, Siebelink, & Kok, 2009). Since we face an obesity epidemic, it is worthwhile to explore the long-term effects of eating rate on energy balance and which additional food properties, besides macronutrient composition, influence eating rate. Such information could be used in weight maintaining or weight reduction strategies, by creating awareness on the effects of eating rate on food and energy intake. Simultaneously, it poses a challenge for the food industry to develop palatable foods with a low eating rate, to increase their satiating power, without increasing energy density.

References

Anderson, J. W., Baird, P., Davis, R. H., Jr., Ferreri, S., Knudtson, M., Koraym, A., et al. (2009). Health benefits of dietary fiber. *Nutrition Reviews, 67*(4), 188–205.

Andrade, A. M., Greene, G. W., & Melanson, K. J. (2008). Eating slowly led to decreases in energy intake within meals in healthy women. *Journal of the American Dietetic Association, 108*(7), 1186–1191.

Bellisle, F., Lucas, F., Amrani, R., & Le Magnen, J. (1984). Deprivation, palatability and the micro-structure of meals in human subjects. *Appetite, 5*(2), 85–94.

Bes-Rastrollo, M., van Dam, R. M., Martinez-Gonzalez, M. A., Li, T. Y., Sampson, L. L., & Hu, F. B. (2008). Prospective study of dietary energy density and weight gain in women. *American Journal of Clinical Nutrition, 88*(3), 769–777.

Blundell, J. E., & MacDiarmid, J. I. (1997). Fat as a risk factor for overconsumption: Satiation, satiety, and patterns of eating. *Journal of the American Dietetic Association, 97*(Suppl. (7)), S63–S69.

Bobroff, E. M., & Kissileff, H. R. (1986). Effects of changes in palatability on food intake and the cumulative food intake curve in man. *Appetite, 7*(1), 85–96.

Caputo, F. A., & Mattes, R. D. (1992). Human dietary responses to covert manipulations of energy, fat, and carbohydrate in a midday meal. *American Journal of Clinical Nutrition, 56*(1), 36–43.

Cecil, J. E., Francis, J., & Read, N. W. (1998). Relative contributions of intestinal, gastric, oro-sensory influences and information to changes in appetite induced by the same liquid meal. *Appetite, 31*(3), 377–390.

Cecil, J. E., Francis, J., & Read, N. W. (1999). Comparison of the effects of a high-fat and high-carbohydrate soup delivered orally and intragastrically on gastric emptying, appetite, and eating behaviour. *Physiology and Behavior, 67*(2), 299–306.

Cordain, L., Eaton, S. B., Sebastian, A., Mann, N., Lindeberg, S., Watkins, B. A., et al. (2005). Origins and evolution of the Western diet: Health implications for the 21st century. *American Journal of Clinical Nutrition, 81*(2), 341–354.

de Castro, J. M. (2004). Dietary energy density is associated with increased intake in free-living humans. *The Journal of Nutrition, 134*(2), 335–341.

Doucet, E., & Tremblay, A. (1997). Food intake, energy balance and body weight control. *European Journal of Clinical Nutrition, 51*(12), 846–855.

Drewnowski, A. (1995). Energy intake and sensory properties of food. *American Journal of Clinical Nutrition, 62*(Suppl. (5)), 1081S–1085S.

Epstein, L. H., Parker, L., McCoy, J. F., & McGee, G. (1976). Descriptive analysis of eating regulation in obese and nonobese children. *Journal of Applied Behavior Analysis, 9*(4), 407–415.

French, S. J., & Cecil, J. E. (2001). Oral, gastric and intestinal influences on human feeding. *Physiology and Behavior, 74*(4–5), 729–734.

Guss, J. L., & Kissileff, H. R. (2000). Microstructural analyses of human ingestive patterns: From description to mechanistic hypotheses. *Neuroscience and Biobehavioral Reviews, 24*(2), 261–268.

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*(8040), 679–682.

Hill, S. W., & McCutcheon, N. B. (1984). Contributions of obesity, gender, hunger, food preference, and body size to bite size, bite speed, and rate of eating. *Appetite, 5*(2), 73–83.

Holt, S. H., Miller, J. C., Petocz, P., & Farmakalidis, E. (1995). A satiety index of common foods. *European Journal of Clinical Nutrition, 49*(9), 675–690.

Hulshof, K.F.A.M., Ocké, M., van Rossum, C. T. M., Buurma-Rethans, E. J. M., Brants, H. A. M., Drijvers, J. J. M. M., et al. (2003). *Results of the National Food Consumption Survey 2003* (No. RIVM report 350030002/2004).

Kissileff, H. R., Zimmerli, E. J., Torres, M. I., Devlin, M. J., & Walsh, B. T. (2008). Effect of eating rate on binge size in Bulimia nervosa. *Physiology and Behavior, 93*(3), 481–485.

Kral, J. G., Buckley, M. C., Kissileff, H. R., & Schaffner, F. (2001). Metabolic correlates of eating behavior in severe obesity. *International Journal of Obesity and Related Metabolic Disorders, 25*(2), 258–264.

Kral, T. V., & Rolls, B. J. (2004). Energy density and portion size: Their independent and combined effects on energy intake. *Physiology and Behavior, 82*(1), 131–138.

Laessle, R. G., Lehrke, S., & Duckers, S. (2007). Laboratory eating behavior in obesity. *Appetite, 49*(2), 399–404.

Lavin, J. H., French, S. J., Ruxton, C. H., & Read, N. W. (2002). An investigation of the role of oro-sensory stimulation in sugar satiety? *International Journal of Obesity and Related Metabolic Disorders, 26*(3), 384–388.

Levitsky, D. A., Obarzanek, E., Mrdjenovic, G., & Strupp, B. J. (2005). Imprecise control of energy intake: Absence of a reduction in food intake following overfeeding in young adults. *Physiology and Behavior, 84*(5), 669–675.

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 of Clinical Nutrition, 88*(6), 1560–1566.

Malik, V. S., Schulze, M. B., & Hu, F. B. (2006). Intake of sugar-sweetened beverages and weight gain: A systematic review. *American Journal of Clinical Nutrition, 84*(2), 274–288.

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. *Behaviour Research and Therapy, 45*(10), 2349–2359.

Mattes, R. (2005). Soup and satiety. *Physiology and Behavior, 83*(5), 739–747.

Mattes, R. D., & Rothacker, D. (2001). Beverage viscosity is inversely related to postprandial hunger in humans. *Physiology and Behavior, 74*(4–5), 551–557.

NEVO-tabel. (2006). *Dutch food composition table*. The Hague: Netherlands Nutrition Center.

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*(3), 117–124.
Rolls, E. T. (2007). Sensory processing in the brain related to the control of food intake. *The Proceedings of the Nutrition Society, 66*(1), 96–112.
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 and Related Metabolic Disorders, 27*(11), 1405–1410.
Savage, J. S., Marini, M., & Birch, L. L. (2008). Dietary energy density predicts women's weight change over 6 y. *American Journal of Clinical Nutrition, 88*(3), 677–684.
Slimani, N., Deharveng, G., Southgate, D. A. T., Biessy, C., Chajes, V., van Bakel, M. M. E., et al. (2009). Contribution of highly industrially processed foods to the nutrient intakes and patterns of middle-aged populations in the European prospective investigation into cancer and nutrition study. *European Journal of Clinical Nutrition, 63*(S4), S206–S225.
Strien, T. V. (1986). *Eating behaviour personality traits and body mass*. (Unpublished PhD Thesis). Landbouw Hogeschool, Wageningen.
Stubbs, R. J., & Whybrow, S. (2004). Energy density, diet composition and palatability: Influences on overall food energy intake in humans. *Physiology and Behavior, 81*(5), 755–764.
Viskaal-van Dongen, M., de Graaf, C., Siebelink, E., & Kok, F. J. (2009). Hidden fat facilitates passive overconsumption. *Journal of Nutrition, 139*(2), 394–399.
Yeomans, M. R. (1996). Palatability and the micro-structure of feeding in humans: The appetizer effect. *Appetite, 27*(2), 119–133.
Zijlstra, N., de Wijk, R. A., Mars, M., Stafleu, A., & de Graaf, C. (2009). Effect of bite size and oral processing time of a semisolid food on satiation. *American Journal of Clinical Nutrition, 90*(2), 269–275.
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 (London), 32*(4), 676–683.