Food Quality and Preference 90 (2021) 104156

Contents lists available at ScienceDirect

Food Quality and Preference

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

Olfactory priming for eating behavior – The influence of non-conscious exposure to food odors on specific appetite, food preferences and intake

Paulina Morquecho-Campos [*], Kees de Graaf, Sanne Boesveldt

Division of Human Nutrition and Health, Wageningen University, 6708 WE Wageningen, the Netherlands

ARTICLE INFO

Keywords:
Olfaction
Implicit exposure
Unconsciousness
Food consumption
Congruency

ABSTRACT

Sensory food cues in our surroundings, such as odors, trigger decisions that may lead to (over)eating. These cues occur mainly outside of people's awareness. Therefore, it is crucial to better understand the effect of (non-consciously exposure of) food odors on behavioral responses. Moreover, sensory-specific appetite suggests that food odor exposure may enhance appetite for products with similar properties in taste and calorie content, inferring that we can detect nutrient content of the food through our sense of smell. Our previous research showed that conscious exposure to macronutrient-related odors influenced specific appetite but not food preferences or intake. However, eating behavior responses may differ depending on the level of awareness of the odor cue. Therefore, in our current study, we aimed to determine the influence of non-conscious exposure to macronutrient-related odors on specific appetite, food preferences and food intake. 34 healthy, normal-weight and unrestrained Dutch females underwent four sessions where they were non-consciously exposed to odors representing food high in carbohydrates, protein and fat, and low-calorie foods. Eating behavior was assessed through a specific appetite questionnaire, a computer task on macronutrient and taste food preferences, and actual food intake by means of a salad bar which included toppings representing the different macronutrients. Results show that non-conscious exposure to macronutrient-signaling odors does not influence congruent appetite, food preferences nor food intake of a main meal. Follow-up research should focus on different odor exposure (intensity and exposure time) and outcomes measures to have a better understanding of olfactory priming on eating behavior.

1. Introduction

We are constantly exposed to sensory cues without being consciously aware of them: food advertisements by the road, nutritional advice on the radio, food aromas in the supermarket, etc. These sensory cues can steer our eating behavior towards (un)healthy decisions (Köster, 2009; Stroebele & De Castro, 2004). However, the exact nature of the influence of these food cues on eating behavior has yet remained unclear and awareness may differentially affect eating responses.

Non-conscious exposure to food cues can activate a mental representation triggering cognitive and behavior responses, known as priming (Bargh, 2006; Tulving & Schacter, 1990). In particular, olfactory priming may influence mood, memory, consumer and eating behavior (De Luca & Botelho, 2019; Smeets & Dijksterhuis, 2014, for reviews). Various eating behavior outcomes such as appetite, food choice and/or intake have been investigated in relation to olfactory priming. Literature thus far suggests that *non-conscious* exposure to odors does not influence specific appetite (Proserpio, de Graaf, Laureati, Pagliarini, & Boesveldt, 2017). However, it may impact food choices (Chambaron, Chisin, Chabanet, Issanchou, & Brand, 2015; de Wijk & Zijlstra, 2012; Gaillet, Sulmont-Rossé, Issanchou, Chabanet, & Chambaron, 2013; Gaillet-Torrent, Sulmont-Rossé, Issanchou, Chabanet, & Chambaron, 2014). E.g. in a series of studies, Gaillet et al. have shown that starters and desserts containing fruit and vegetables were selected more frequently from a menu when participants were non-consciously exposed to melon and/or pear odor (Gaillet et al., 2013; Gaillet-Torrent et al., 2014).

Furthermore, others have shown that non-conscious exposure may also influence congruent food intake, e.g. chocolate rice upon high-calorie-related odor exposure (Proserpio et al., 2017, 2019). Moreover, results from a reaction time task demonstrated that *only non-conscious* odor exposure led to attentional biases towards foods, as compared to conscious odor exposure (Mas, Brindisi, Chabanet, Nicklaus, & Chambaron, 2019).

Conversely, *conscious* odor exposure may influence self-reported

* Corresponding author at: Division of Human Nutrition and Health, Wageningen University, Stippeneng 4 (Building 124), 6708 WE Wageningen, the Netherlands.
E-mail address: paulina.morquechocampos@wur.nl (P. Morquecho-Campos).

https://doi.org/10.1016/j.foodqual.2020.104156
Received 22 June 2020; Received in revised form 10 December 2020; Accepted 15 December 2020
Available online 4 January 2021

appetite (Ferriday & Brunstrom, 2011; Ramaekers, Boesveldt, Gort, et al., 2014), but not food preference and intake (Zoon, He, de Wijk, de Graaf, & Boesveldt, 2014).

Awareness of the odor may thus play a crucial role in the type of response it exerts (McCrickerd & Forde, 2016; Smeets & Dijksterhuis, 2014). On one hand, barely detectable and unattended odors may act as prime and trigger congruent food choice and intake (Chambaron et al., 2015; Gaillet et al., 2013; Gaillet-Torrent et al., 2014; Proserpio et al., 2017, 2019), as these decision-making processes may occur at a non-conscious level (Bargh & Ferguson, 2000; Köster, 2009). On the other hand, conscious odors may mainly induce sensory-specific appetite (Ferriday & Brunstrom, 2011; Ramaekers, Boesveldt, Gort, et al., 2014; Zoon et al., 2014). Awareness of the odor cue and/or the congruent appetite response may trigger cognitive control (such as self-regulation and inhibition mechanisms) which could interrupt the meal process at this stage and prevents the translation from appetite into further food choice and intake (Boesveldt & de Graaf, 2017).

Sensory-specific appetite (SSA) infers that food odor cues may convey information related to the macronutrient content, based on the taste and calorie content, of the associated food and thereby may induce congruent appetite and possibly even food choice and intake (Ferriday & Brunstrom, 2011; Ramaekers, Boesveldt, Gort, et al., 2014; Ramaekers, Boesveldt, Lakemond, van Boekel, & Luning, 2014; Zoon, de Graaf, & Boesveldt, 2016). Our own previous research showed that conscious exposure to macronutrient-related odors increased congruent appetite mainly after protein-related odor exposure, but did not impact food preferences or actual food intake (Morquecho-Campos, de Graaf, & Boesveldt, 2020). Therefore, in the current study we aimed to investigate how non-conscious macronutrient-related odors exposure would impact specific appetite, food preferences and intake. We hypothesized that non-conscious odor exposure would enhance congruent food preferences and intake. Specifically, we hypothesized that macronutrient preferences and food intake would increase in a congruent manner after exposure to macronutrient-related odors (e.g. exposure to protein-related odors will increase preferences for foods high in protein such as ham, chicken, compared to incongruent food products such as bread/croutons for carbohydrates, nuts for fat or cucumber for low-calorie). However, non-conscious odor exposure would not influence self-reported appetite ratings for congruent food products.

2. Materials and methods

2.1. Participants

Normal-weight Dutch females between 18 and 35 years old were recruited from Wageningen and the surroundings. Initially, participants were invited to an information and screening session, during which they provided written informed consent and filled out a questionnaire to determine their eligibility. Participants with a normal sense of smell (scoring ≥ 12 on the 16 items Sniffin' Sticks odor identification test (Oleszkiewicz, Schriever, Croy, Hähner, & Hummel, 2019), self-reported normal sense of taste, and unrestrained eaters on the Dutch Eating Behavior Questionnaire, DEBQ (van Strien, Frijters, Bergers, & Defares, 1986) were included. Participants were excluded when they: were a smoker; disliked the food products used in the study (<40 on 100 mm visual analogue scale, VAS); had any dietary restriction towards specific foods (self-imposed or otherwise; e.g. vegetarian, vegan); used medication other than paracetamol and hormonal contraceptives; were pregnant or had the intention to become pregnant during the experiment or were currently breastfeeding; reported weight loss or weight gain of more than 5 kg or following a special diet in the two months prior to the study; or participated in our previous study (Morquecho-Campos et al., 2020). Moreover, taste ability and color blindness were assessed during the screening session by means of Taste Strips and Ishihara's color test, respectively (Ishihara, 1951; Landis et al., 2009; Mueller et al., 2003). These measures were taken as bogus tasks to distract potential participants from the true aim of the study that involved odor perception but were not considered as inclusion/exclusion criteria. The alternative goal communicated to participants was that we aimed to investigate the role of hunger, food cue exposure, and satiety on abilities of logic reasoning by means of psychometric tasks.

The sample size calculation was based on previous research (Chambaron et al., 2015; Gaillet-Torrent et al., 2014; Gaillet et al., 2013; Proserpio et al., 2017; Ramaekers, Boesveldt, Gort, et al., 2014; Zoon et al., 2016), resulting in a total of 34 participants included in the study (Table 1). Participants were compensated at the end of the study for their contribution. The study was conducted in accordance with the Declaration of Helsinki (revised in 2013) and approved by the Medical Ethical Committee of Wageningen University (NL 69840.081.19). This trial was pre-registered at the Netherlands Trial Register as NL7742 (https://www.trialregister.nl/trial/7742).

Table 1
Characteristics of the 34 participants included in the study.

Characteristic	Mean ± SD (range)
Age (years)	21.3 ± 1.8 (18 – 26)
BMI (kg/m^2)	21.5 ± 1.7 (18.8–24.7)
Odor Identification Score	14.1 ± 1.0 (12–16)
Restrained Score (DEBQ)	2.4 ± 0.7 (1.0–3.3)

2.2. Procedure

This study had a cross-over intervention design, where participants were (non-consciously) exposed to three macronutrients-related odors (i.e., carbohydrates, protein and fat) and a low-calorie-related odor as a control condition. Participants visited the test location four times, once for each odor condition, with at least two days in between. Test sessions took place around lunch time (11.30–14.00) and participants attended their sessions at the same time. Participants were asked not to eat or drink (except water) at least three hours before the test sessions, to be in a mild hunger state.

Fig. 1 provides an overview of the procedure of each test session. On arrival at each test session, participants rated their general appetite and specific appetite (non-odorized room). Then, they were escorted to a new room (odorized room) where they performed a psychometric task (#1) for 3 min. This room was scented with a non-consciously detectable concentration of the different odors (perceived intensity < 35 mm on a 100 mm VAS, detailed information can be found in Section 2.3). After the first odor exposure, participants went back to the non-odorized room where they rated their general and specific appetite again and performed a computer-based food preference task. Subsequently, they went back to the same odorized room and performed again a psychometric task (#2) for 3 min. Then, participants were escorted to a dining room where they rated their general appetite and were provided with a salad bar lunch by which their *ad libitum* food intake was covertly measured. After the participants finished their lunch (~20 min), they performed a final psychometric task (#3). After each psychometric task, participants rated their stress level after the psychometric task and the perceived level of difficulty of the psychometric task.

At the end of the last session, participants were debriefed. They were asked about their impression of the aim of the study and whether they had perceived an odor in the odorized rooms (where they had performed the first two psychometric tasks) in any of the test sessions. After completing the debriefing questionnaire, they were informed about the true aim, and were presented with the four odors to rate on various attributes.

2.3. Odor stimuli

Based on our previous study (Morquecho-Campos et al., 2020), pilot studies and familiarity for Dutch participants, we selected one odor per

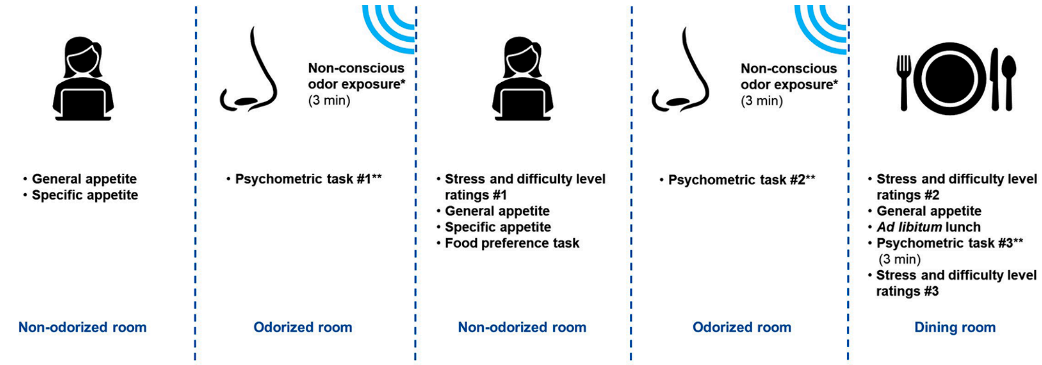

Fig. 1. Procedure for each test session. *Participants were exposed twice to the same odor within the same session. **Psychometric tasks were bogus tasks as part of the alternative goal to keep participants naïve from the real aim of the study.

category and determined appropriate intensities: bread (Symrise 205361; 8% in propylene glycol, PG) for carbohydrates; duck (Symrise 619322; 0.05% in PG) for protein; butter (IFF 10922603; 60% in PG) for fat; cucumber (IFF 15311331; 100%) for the low-calorie category. The odors were distributed in air-conditioned rooms by means of vaporizers (Iscent, Zeewolde, The Netherlands). Pilot studies were carried out to achieve a non-consciously detectable concentration, which we defined as a perceived intensity lower than 35 mm on a VAS. These pilot studies consisted of several short sessions where participants (n = 10 per session, which did not participate in the actual study) were exposed to an odor dispersed in the odorized room. Participants were asked about their awareness of any odor present in the room, and if so, to assess the intensity of the ambient odor (on a 100 mm VAS anchored from "Not at all" to "Very much"). Only one participant was allowed in the room at the same time. The final dispersion frequency and perceived intensity of the odors can be found in the Supplementary materials (Table S1).

Odors were prepared every week and stored in the fridge until the morning of the test session. On the morning of the test session, the odor stimuli were taken out of the fridge and stored at room temperature. After the test sessions of each day were completed, the room was ventilated, the surfaces were cleaned, and the odor was fully purged overnight.

2.4. Measurements

2.4.1. General and specific-sensory appetite

General appetite was determined by assessing hunger, fullness, prospective consumption, desire to eat, and thirst on 100 mm VAS anchored by "Not at all" to "Very much". The "General appetite score" variable was computed as the average of hunger, desire to eat, prospective consumption, and the inverse fullness' score (100 – fullness).

Specific-sensory appetite was assessed by rating 'How much would you like to eat *'[specific product]'* at this moment?' on a 100 mm VAS anchored by "Not at all" to "Very much". Specific products consisted of 12 food items, 3 per macronutrient category, which either did or did not match the odor stimuli (congruent/incongruent): pasta, bread, and corn for carbohydrates; chicken, ham, and beef for protein; bacon, nuts, and cheese for fats; cucumber, tomato, and melon for low-calorie food products.

Table 2
Food products offered at the *ad libitum* lunch.

Category	Food	Energy (kcal/100 g)	Carbohydrates (%)	Protein (%)	Fat (%)
Carbohydrates	Croutons	455	**57.1**	11.4	29.7
	Corn	71	**59.2**	15.2	17.7
Protein	Chicken strips	105	15.2	**64.8**	21.4
	Ham strips	115	1.0	**69.6**	27.4
Fat	Mixed nuts	625	4.8	11.5	**81.4**
	48 + Gouda Cheese	360	0.0	25.6	**75.0**
Low-calorie	Cucumber	13	40.0	21.5	27.7
	Cherry tomatoes	30	53.3	12.0	24.0
Base	Lettuce	13	46.2	30.8	6.9
Dressing	Natural salad dressing	40	9.5	0.1	0.1

Numbers in bold emphasize the highest contribution to the total energy content of the food products, which represents their respective food product category.

2.4.2. Food preferences

Food preferences were measured by means of the Macronutrient and Taste Preference Ranking Task (MTPRT), a validated computer-based task (de Bruijn, de Vries, de Graaf, Boesveldt, & Jager, 2017). This task consists of rating the liking of 32 food products (represented by pictures with labels) and ranking the food products (represented only by pictures) according to participants' desire to eat at that moment. These foods are divided into four macronutrient categories- carbohydrates, protein, fat, and low-calorie- with each category consisting of 4 sweet and 4 savory foods, except the protein category (only savory). Liking ratings were aggregated per macronutrient and taste category for analyses. Macronutrient preference ranking score can range between 1 and 4, while taste preference scores can range between 1.5 and 3.5: higher scores representing a higher preference. As sweet and savory preference ranking scores obtained in this task are (by definition) opposite to each other, we reported only the savory taste results.

2.4.3. Food intake

The *ad libitum* lunch consisted of a salad bar, with 2 options per macronutrient (i.e., carbohydrates, protein and fat) and 2 low-calorie products, see Table 2. The toppings for the macronutrient categories contained at least 50% of the total energy derived from the specific macronutrient category and toppings in the low-calorie category contained no more than 60 kcal/100 g (de Bruijn et al., 2017; RIVM, 2019). All food products are commercially available and familiar in the Dutch diet. Participants received a bowl with a fixed amount of salad (80 g) and were instructed to choose as many toppings and the quantity as they wanted. They also received 28 g of a natural salad dressing to add to their salad (if necessary), and a glass of water (150 mL) that they were instructed to finish during the lunch. Only one participant was allowed in the buffet area at a time and they could only visit the buffet area once. Participants were instructed to sit in the dining area, which did not face the buffet area, and to eat until they felt comfortably satiated. They were not obliged to finish their plate. The buffet was continuously refilled, to ensure a constant volume on each topping tray. Food intake was covertly measured by weighing the trays which contained each topping before and after each participant 'built' their salad and by weighing the remaining amount on the plate of the participants after eating.

2.4.4. Odor attribute ratings – debriefing session

At the end of the last test session, participants assessed the odor on liking, intensity, familiarity, intention to eat a product with that odor, and mouth-watering sensation on a 100 mm VAS anchored by "Not at all" to "Very much". They were also asked to identify the odor among a list of (food) products, including 'odorless', by a multiple forced-choice task ('Which of the following label(s) best fits the odor?') and to assess the odor-label association ('How well do you think this smell corresponds to *'[specific label]'*) on a 100 mm VAS.

2.4.5. Psychometric task- as bogus task

The psychometric tasks consisted of four different type of tasks: numerical, inductive, verbal, and logical reasoning with figures. In each test session, participant randomly performed a different type of psychometric task. The psychometric tasks were retrieved from 123test.com and "501 challenging logic and reasoning problems" (123test.com, n.d.; LearningExpress (Organization) (2005)). These tasks were moderate to high in difficulty to be in line with our alternative goal. However, in order to control any potential effects of different stress levels on our outcomes, the level of these tasks was similar across types of psychometric tasks and sessions. Performing these psychometric task could modify the level of stress of the participant which may affect food choice or intake (Groesz et al., 2012; Yau & Potenza, 2013). Therefore, the stress levels after the performance of each task and the difficulty of each psychometric task were measured and added as covariates to our models.

2.5. Statistical analyses

All statistical analyses were carried out in RStudio (RStudio Team, 2016), and graphs were made using GraphPad Prism 5.0 (GraphPad Prism Software). Results with a p value lower than 0.05 were considered statistically significant.

All analyses consisted of linear mixed models, carried out using the *lme4* statistical package in R (Bates, Mächler, Bolker, & Walker, 2015). The best fitting models were selected on the basis of parsimony following a backward approach. Homoscedasticity and normal distribution of error terms, and correct specifications of the fixed and random parts of the model were checked for each model. Post-hoc tests with a Bonferroni correction, by means of the *lsmeans* statistical package (Lenth, 2016), were performed when the main effects or interaction were significant.

Odor attribute ratings were analyzed as a dependent variable, with odor as fixed effects and participants and evaluation order as random effects. The liking of food products was analyzed as a dependent variable, with food product as fixed effects and participants as random effects. This data is shown in Tables S2 and S3 of the Supplementary materials.

Data was labeled as congruent/incongruent, depending on the food products used relative to the odor category. For example, specific appetite or food intake of protein-rich products (such as ham, chicken or meat) were considered congruent after exposure to a protein-related odor (meat), but labeled as incongruent after exposure to other odor categories.

For all the models, participants and test sessions nested in allocation groups (12 allocation groups based on participants' availability: 9 groups consisted on 3 participants and 3 groups on 1, 2 and 4 participants, respectively) were evaluated as random factors.

2.5.1. Change in specific sensory appetite

Change in specific sensory appetite (SSA; calculated as difference in the specific appetite ratings before versus after odor exposure) was analyzed as dependent variable. Odor category, (in)congruency of food product, and their interaction were included as fixed factors. Participants were included as random factor. Liking of food products (assessed during the screening session on a 100 mm VAS), specific appetite before odor exposure, individual odor attribute ratings (assessed during the debriefing on a 100 mm VAS), stress levels and difficulty of the psychometric task #1, general appetite score and thirst rating before and after the first odor exposure, and personal characteristics (age, BMI, DEBQ, and Sniffin' sticks) were included as covariates.

2.5.2. Food preferences

Congruency was determined by the match between odor exposure category and each macronutrient score analyzed. Each macronutrient liking and ranking score was analyzed as dependent variable in separate linear mixed models. Congruency was included as fixed factor in the liking and ranking results of the macronutrient models. Odor category was included as fixed factor in the liking and ranking results of the (savory) taste models. Participants were included as random factor for all the models. Individual odor attribute ratings, stress levels and difficulty of the psychometric task #1, general appetite score and thirst rating after the first odor exposure, and personal characteristics were entered as covariates in both macronutrient and savory taste preferences score's models.

2.5.3. Food intake

Food intake was analyzed in three ways. Firstly, to determine the influence of odor exposure on overall food intake, total food intake (in g and kcal) was analyzed as dependent variable, with odor category as fixed factor. Secondly, to determine the influence of odor exposure on (in)congruent food intake, food intake (in g and kcal) was analyzed as dependent variable, and congruency (depending on the food products selected and eaten relative to the odor condition) as a fixed factor. Thirdly, to determine the influence of odor exposure on specific food intake of the different product categories, food intake (in g and kcal) was analyzed as dependent variable, with odor category, food product category, and their interaction were included as fixed factors. In the models of the first part, participants were included as random factors. Allocation groups were additionally included as random factor in the models of the second and third part.

Liking of food products available in the *ad libitum* lunch (assessed during the screening session on a 100 mm VAS), individual odor attribute ratings, stress levels and difficulty of the psychometric task #2, general appetite score and thirst rating after the second odor exposure, and personal characteristics were entered as covariates in all the models.

Moreover, Pearson correlation analyses were performed to determine the correlation between food preferences score and food intake (in g and kcal). The correlation analyses considered participants as random factors, using the residuals of a mixed model with food intake (in g and kcal) as a dependent variable and participants as random effects. The residuals of those models were correlated with food preferences scores.

3. Results

3.1. Change in specific appetite (SSA)

There was a significant interaction between odor category and congruency ($F\ (3,1588) = 2.76$, $p = 0.041$; mixed model included liking of the food product, specific appetite before odor exposure, and general appetite score after the first odor exposure as covariates; Fig. 2). However, Bonferroni post-hoc tests did not reveal any significant difference between the respective conditions (all $p > 0.05$).

3.2. Food preferences

Odor exposure did not influence liking for congruent food products (Table 3**A**). Similarly, odor exposure did not affect preference ranking for congruent food products (Table 3**B**).

Liking for savory-tasting food products was not influenced by odor

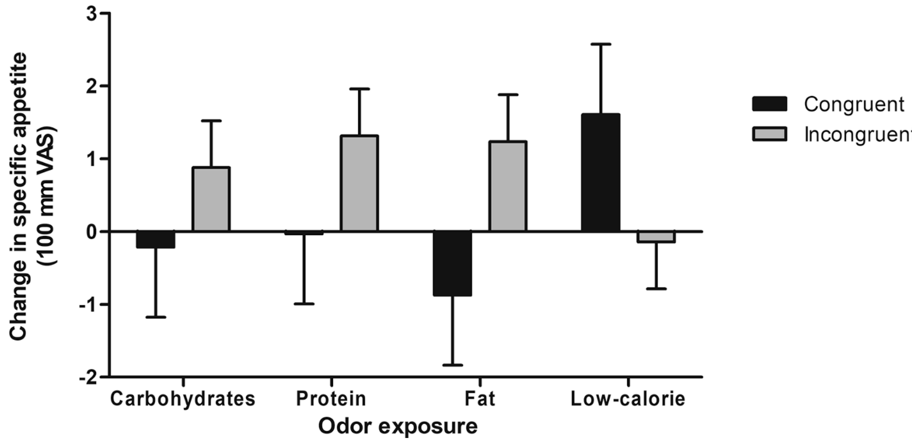

Fig. 2. Change in specific appetite upon odor exposure for congruent (black color) and incongruent food products (light gray color). Values are expressed as mean and standard error.

Table 3
Ratings of liking (on a 100 mm VAS) and preference score (score range: 1 – 4) of each macronutrient after exposure to (in)congruent odors. Values are expressed as mean and standard error.

Macronutrient	Congruent condition	Incongruent condition	Statistical information
A) Liking*			
Carbohydrates	67.8 ± 2.00	66.9 ± 1.93	F (1,100) = 1.59, p = 0.21
Protein	60.6 ± 2.55	61.4 ± 2.47	F (1,100) = 0.63, p = 0.43
Fat	71.3 ± 1.83	71.3 ± 1.75	F (1,100) = 0.001, p = 0.98
Low-calorie	67.7 ± 2.29	67.1 ± 2.23	F (1,101) = 0.56, p = 0.46
B) Preference score**			
Carbohydrates	2.53 ± 0.07	2.50 ± 0.07	F (1,101) = 0.57, p = 0.45
Protein	2.27 ± 0.11	2.35 ± 0.10	F (1,98) = 3.61, p = 0.06
Fat	2.73 ± 0.07	2.77 ± 0.07	F (1,101) = 1.57, p = 0.21
Low-calorie	2.42 ± 0.11	2.39 ± 0.11	F (1,98) = 0.41, p = 0.53

* Covariates included in the liking models: general appetite score after the first odor exposure was included as covariate in the carbohydrates, protein and fat models; the low-calorie model did not include any covariate.
** Covariates included in the preference score models: no covariates were included in the models for carbohydrates and fat; intention to eat a product with that odor, mouth-watering sensation upon that odor and general appetite score after the first odor exposure were included in the protein and low-calorie models.

exposure (Table 4). The ranking of savory-tasting foods was influenced by odor exposure (Table 4). However, Bonferroni post-hoc tests did not reveal any significant difference between the respective conditions.

3.3. Food intake

Firstly, total food intake (in g and kcal) did not differ significantly after exposure to the different macronutrient-related odors (Table 5).

Secondly, food intake did not differ significantly between congruent versus incongruent food products after odor exposure (g: F (1,1052) = 0.04, p = 0.85; kcal: F (1,1052) = 0.08, p = 0.77; liking of food products was included as covariate in both mixed models).

Table 4
Ratings of liking (on a 100 mm VAS) and preference score (score range: 1.5 – 3.5) of savory taste after odor exposure. Values are expressed as mean and standard error.

Odor category	Liking for savory- tasting foods	Preference score for savory-tasting foods
Carbohydrates	63.5 ± 1.77	2.24 ± 0.06
Protein	63.4 ± 1.78	2.21 ± 0.05
Fat	63.3 ± 1.78	2.30 ± 0.06
Low-calorie	64.0 ± 1.78	2.30 ± 0.06
Statistical information	F (3,98) = 0.30, p = 0.83*	F (3,99) = 3.38, p = 0.02**

* General appetite score after the first odor exposure was included as covariate.
** No covariates were included in this model. Bonferroni post-hoc tests did not reveal any significant difference between these conditions.

Thirdly, there was no interaction between odor category and food product category (g: F (9,1038) = 0.58, p = 0.81, Fig. 3**A**; kcal: F (9,1038) = 0.63, p = 0.77, Fig. 3**B**; liking of food products was included as covariate in both mixed models). Overall, the consumption (in grams) of low-calorie food products was significantly higher compared to the intake of carbohydrates, protein and fat (F (3,1049) = 196.56, p < 0.0001; Fig. 3**A**), and the caloric intake of fat products was significantly higher compared to that of the other food product categories (F (3,1049) = 171.76, p < 0.0001; Fig. 3**B**).

Food preference scores were positively correlated with food intake (g: r (542) = 0.16, p = 0.0003; kcal: r(542) = 0.27, p < 0.0001).

3.4. Debriefing - odor awareness

All the participants believed that the aim of the study was related to the psychometric tasks, stress levels, and/or hunger state. None of the participants reported a link between the measurements performed and the ambient odors. The data from the debriefing questionnaire was classified into four score categories as suggested by Mors, Polet, Vingerhoeds, Perez-Cueto, and de Wijk (2018). Participants did not perceive the odor in 89.0% of the test sessions, while in 2.2% of them they perceived an odor and correctly identified it. In a further 8.1% of test sessions, participants detected an odor but could not name it, and in

Table 5
Total food intake in g and kcal after exposure to the different macronutrient-related odors. Values are expressed as mean and standard error.

Odor category	Total food intake (g)	Total food intake (kcal)
Carbohydrates	423 ± 22.7	540 ± 41.2
Protein	425 ± 22.6	494 ± 40.5
Fat	442 ± 22.9	529 ± 41.2
Low-calorie	425 ± 22.6	499 ± 40.5
Statistical information	$F(3,92) = 0.51$, $p = 0.68$*	$F(3,95) = 0.78$, $p = 0.53$**

* General appetite score after the second odor exposure was included as covariate.
** No covariate contributed to the fit of this model.

the remaining 0.7% of the test sessions participants perceived an odor but were unable to correctly identify it.

4. Discussion and conclusion

4.1. Discussion

The current study aimed to determine the influence of non-conscious exposure to macronutrient-related odors on measures of eating behavior. Based on available literature, we hypothesized that non-conscious exposure would not impact explicit responses such as self-reported appetite, but would influence food preferences and intake. Our results show that non-conscious odor exposure did not impact appetite (albeit contrary to our hypotheses), and did not modify food preference nor food intake in a salad bar setting.

Appetite feelings can be induced by external sensory cues and may lead to an in increase in searching and wanting to consume specific foods (de Graaf, Blom, Smeets, Stafleu, & Hendriks, 2004; Egecioglu et al., 2011). Therefore, when we are consciously exposed to food cues such as odors, our appetite for congruent foods may increase, demonstrating olfactory sensory-specific appetite (Ferriday & Brunstrom, 2011; Morquecho-Campos et al., 2020; Ramaekers, Boesveldt, Gort, et al., 2014; Ramaekers, Boesveldt, Lakemond, van Boekel, & Luning, 2014; Zoon et al., 2016). However, in line with the current study, results from Proserpio et al. also showed no influence of non-conscious odor exposure on specific appetite (Proserpio et al., 2017). Appetite feelings are measured by explicit, subjective ratings that involve a conscious realization of cravings and external cues (de Graaf et al., 2004; Proserpio et al., 2017). Therefore, sensory-specific appetite may only occur when the odor is being consciously perceived. However, this conscious perception may also activate cognitive processes which can disturb the decision-making beyond the appetizing stage such as choosing foods and consuming a meal (Boesveldt & de Graaf, 2017).

Contrary to our expectations, non-conscious odor exposure did not affect food preferences. Food preference is the choice of one food over other ones (Rozin & Vollmecke, 1986). Previous studies have demonstrated the influence of non-conscious odor exposure on congruent food choices (Chambaron et al., 2015; Gaillet et al., 2013; Gaillet-Torrent et al., 2014). Contrary to our food preference computer-based task, those studies measured food choice by means of a menu or a buffet-style where the participants selected only one option from each course category (starters, main courses, desserts). Such a forced choice procedure could be more naturalistic compared to our (computer-based) ranking task, and provides information of momentary motivation for the chosen food product over the other(s) one(s) (Finlayson, King, & Blundell, 2008). In line with this, and similar to our current study, Mors et al. offered an assortment of different meals where the participants were able to freely select their food, and failed to show an effect of olfactory priming on subsequent food choices (Mors et al., 2018). Free selection (and consumption) of food products might lead to choices based on habits instead of being influenced by olfactory priming. Moreover, the food products displayed in the ranking task vary in a consumption context (e.g. ranking between salty sticks, chocolate bar, cod fillet, and strawberries), which could influence the current preference selection of the products. Food choice behavior is typically closely related to the context or appropriateness of consumption of the selected food and the odor (Chambaron et al., 2015; de Wijk et al., 2018; McCrickerd & Forde, 2016). As explained above, different methodologies (i.e. outcome measures) used to investigate similar eating responses may have led to inconsistent results. This might be a key factor in our current lack of understanding how (and to what extent) odor priming impacts eating behavior. Moreover, previous experiments tended to focus on one outcome only (e.g. Gaillet-Torrent et al., 2014; Chambaron et al., 2015), which from a methodological viewpoint is more simplistic, but lacks understanding of the complete picture of eating behavior.

Furthermore, non-conscious odor exposure did not influence food intake by means of a salad bar, overall nor per congruency according to the odor exposure and congruent macronutrient category or food product category. Food intake is the amount of consumed food in a particular context (de Graaf et al., 2004). Previous research has shown a congruent food intake upon non-conscious odor exposure (Proserpio et al., 2017, 2019). In those studies, food intake was measured as the *ad libitum* intake of a single food.

In line with our previous study (Morquecho-Campos et al., 2020), our current results show that participants selected similar amounts of the available topping regardless of the exposed odor, leading to build their salad in a similar pattern on each test session. This might be related to habits, previous experiences, and expectations on satiation (Birch, 1999; Brunstrom, 2007; Köster, 2009). Interestingly, previous food choice studies suggest an influence of the olfactory priming mainly on starters and desserts (Chambaron et al., 2015; Gaillet et al., 2013;

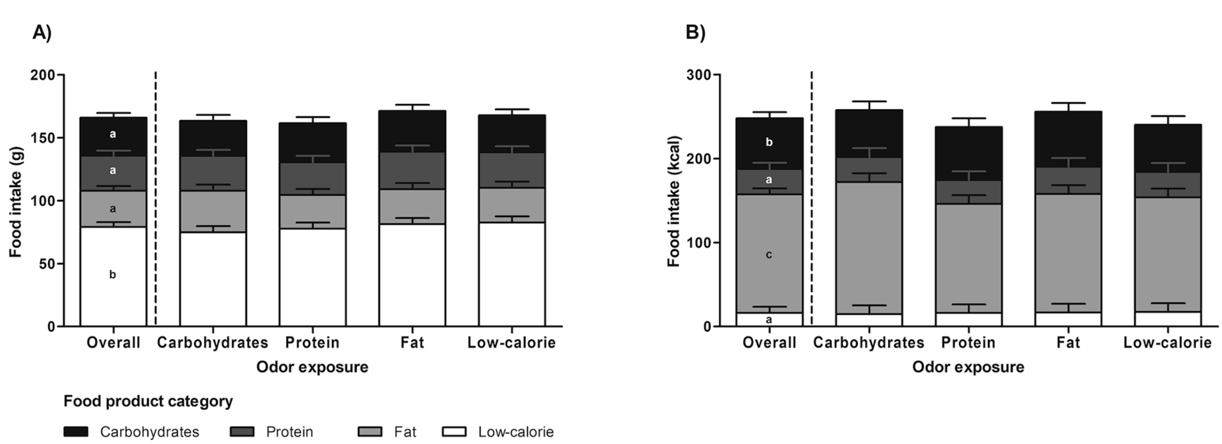

Fig. 3. Intake of food product categories in g (A) and kcal (B) overall and per type of odor exposure. Similar letters indicate no significant differences within food product categories (p greater than 0.05) and are in ascending order (a = lowest intake and c = highest intake). Values are expressed as mean and standard error.

Gaillet-Torrent et al., 2014), but not in the main course (Chambaron et al., 2015; Gaillet et al., 2013; Gaillet-Torrent et al., 2014; Mors et al., 2018). Starters and desserts could be considered as rewarding foods and could be more prone to be driven by external cues, while main courses or meals may reflect more habitual choices in line with overall dietary patterns (Bellisle, 2003; Blundell, De Graaf, Hulshof, Jebb, Livingstone, Lluch, & Westerterp, 2010; de Wijk et al., 2018; Wang, Cakmak, & Peng, 2018). Taken together, this suggests that olfactory priming might not be able to modify regular dietary patterns or main meal selection, but instead may impact rewarding and impulsive eating behavior. Future work should consider the use of other settings such as forced choice response of rewarding food products in a convenience store or in a menu rather than *ad libitum* buffet style, to provide useful insights into participants odor-directed eating behavior. In addition, visual attention may play a beneficial role in understanding decision-making processes (Carrasco, 2011; Krajbich, Armel, & Rangel, 2010; Orquin & Mueller Loose, 2013). Eye movements are linked to perceptual and cognitive processing to reflect visual attention. Visual attention, through the use of eye-tracker, could be useful to detect non-conscious and spontaneous behavior that could help to better understand eating behavior responses (Hummel, Zerweck, Ehret, Salazar Winter, & Stroebele-Benschop, 2017; Seo, Roidl, Müller, & Negoias, 2010; Wang et al., 2018).

It is noteworthy that the olfactory priming studies (Chambaron et al., 2015; de Wijk & Zijlstra, 2012; Gaillet et al., 2013; Gaillet-Torrent et al., 2014; Mas et al., 2019; Mors et al., 2018; Proserpio et al., 2017, 2019) have used different durations and intensities of the odor prime, which may explain some contradictory behavioral responses. Across studies, the range of exposure duration has been very broad (~3–30 min). We decided to expose the participants for the same duration (3 min) as our previous study, which has been shown to be sufficient to enhance congruent appetite when the odor is being actively sniffed (Ferriday & Brunstrom, 2011; Morquecho-Campos et al., 2020; Zoon et al., 2016). However, longer exposure (e.g. 10–30 min, (Chambaron et al., 2015; Gaillet-Torrent et al., 2014; Gaillet et al., 2013; Proserpio et al., 2017, 2019)) may be required for inattentive and low odor exposure to create a mental representation of the cued odor and influence eating behavior. Moreover, for priming to occur, the intensity of the odor cue might be crucial: not too high to become consciously detectable, but at the same time not too low to not be perceived at all. Proserpio, et al. mentioned that the used odors were in detectable but mild concentration with a perceived intensity < 50 mm on VAS (Proserpio et al., 2017, 2019). However, other studies merely mentioned that the intensity of the odor was very low (non-consciously or non-attentively noticeable) without further specification of the perceived intensity (Chambaron et al., 2015; de Wijk & Zijlstra, 2012; Gaillet et al., 2013; Gaillet-Torrent et al., 2014; Mas et al., 2019; Mors et al., 2018). Our current study was performed with low concentrations of the odors (20–30 mm VAS perceived intensity), and the vast majority of the participants did not perceive an odor during the different test sessions, which could indicate that the intensity was too low for the odor to be even physically detected and act as a prime. Taking all of the above together, it shows how differences in methodology used to understand olfactory priming on eating behavior may have led to inconsistent outcomes. Moreover, one of the biggest (methodological) challenges in olfactory priming is to assure that the exposed odor is outside of participants' awareness. In our current study, the intensity of the odors was determined through pilot studies where the participants were aware of the presence of the odor, which likely heightened the perceived intensity, compared to participants in the actual study. The debriefing results confirmed that those participants were not aware of the presence of odors, and that the use of an alternative aim was useful to deviate the attention away from the odor as none of the participants reported a link between the measurements performed and odors. From this we infer that our odor exposure was non-conscious and that a 'priming type 7′ was used (prime was not perceived, the link was not aware, but the participants were aware of the performed measurement) (Dijksterhuis, 2016).

One of the strongest points of this study is the within-subjects design, which considers the individual differences in eating behavior, habits, and odor perception. Moreover, food intake was covertly measured in a salad bar style to offer a more realistic setting. Given our interest in macronutrient-related effects of odors exposure, we deemed a salad bar with different toppings was the best approach to measure intake of the various macronutrient. Our findings may be somewhat limited to generalize by the unrestrained, normal-weight, female study population. For example, obese women increased their sensory specific-appetite and *ad-libitum* intake upon unaware odor exposure (Proserpio et al., 2019).

4.2. Conclusion

Exposure to macronutrient-related food odors outside of participants' awareness did not influence specific appetite, food preferences, or intake of a salad bar. Olfactory priming may not influence habitual main meals such as a lunch. Further work should focus in more detail on differences in methodology (odor exposure and outcomes) to better understand which factors play a role in how olfactory priming influences eating behavior.

Funding

This work was financially supported by the National Council on Science and Technology of Mexico (CONACyT) awarded to PMC.

CRediT authorship contribution statement

Paulina Morquecho-Campos: Conceptualization, Methodology, Resources, Investigation, Formal analysis, Writing - original draft. **Kees de Graaf:** Methodology, Supervision. **Sanne Boesveldt:** Methodology, Writing - review & editing, Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

This work is financed by the National Council on Science and Technology of Mexico (CONACYT) via the scholarship granted to Paulina Morquecho-Campos (No. 589087). We would like to specially acknowledge Kelly Mulder, Celine Jahanshahi, Els Siebelink, and Corine Perenboom for their assistance and support during the setting up of the study and data collection. Thanks to Marieke van Bruinessen for her extensive literature review and to Dr. João Caldas Paulo for her support during data analyses. Moreover, we would like to thank Henriette Fick-Brinkhof and Ineke Klopping-Ketelaars for their support during the development of the study. We would like to thank IFF and Symrise for supplying the odors.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.foodqual.2020.104156.

References

123test.com. (n.d.). Test Yourself! Free high quality psychological tests at test.com. https://www.test.com.

Bargh, J. A. (2006). What have we been priming all these years? On the development, mechanisms, and ecology of nonconscious social behavior. *European Journal of Social Psychology, 36*(2), 147–168. https://doi.org/10.1002/ejsp.336

Bargh, J. A., & Ferguson, M. J. (2000). Beyond behaviorism: On the automaticity of higher mental processes. *Psychological Bulletin, 126*(6), 925–945. https://doi.org/10.1037/0033-2909.126.6.925

Bates, D., Mächler, M., Bolker, B., & Walker, S. (2015). Fitting linear mixed-effects models using lme4. *Journal of Statistical Software, 67*(1), 1–48. https://doi.org/10.18637/jss. v067.i01

Bellisle, E. (2003). Why should we study human food intake behaviour? *Nutrition, Metabolism & Cardiovascular Diseases, 13*(4), 189–193. https://doi.org/10.1016/S0939-4753(03)80010-8

Birch, L. L. (1999). Development of food preferences. *Annual Review of Nutrition, 19*(1), 41–62.

Blundell, J., De Graaf, C., Hulshof, T., Jebb, S., Livingstone, B., Lluch, A., … Westerterp, M. (2010). Appetite control: Methodological aspects of the evaluation of foods. Obesity Reviews, 11(3), 251–270.

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

Brunstrom, J. M. (2007). Associative learning and the control of human dietary behavior. *Appetite, 49*(1), 268–271.

Carrasco, M. (2011). Visual attention: The past 25 years. *Vision Research, 51*(13), 1484–1525. https://doi.org/10.1016/j.visres.2011.04.012

Chambaron, S., Chisin, Q., Chabanet, C., Issanchou, S., & Brand, G. (2015). Impact of olfactory and auditory priming on the attraction to foods with high energy density. *Appetite, 95*, 74–80. https://doi.org/10.1016/j.appet.2015.06.012

de Bruijn, S. E. M., de Vries, Y. C., de Graaf, C., Boesveldt, S., & Jager, G. (2017). The reliability and validity of the Macronutrient and Taste Preference Ranking Task: A new method to measure food preferences. *Food Quality and Preference, 57*, 32–40. https://doi.org/10.1016/j.foodqual.2016.11.003

de Graaf, C., Blom, W. A. M., Smeets, P. M., Stafleu, A., & Hendriks, H. J. (2004). Biomarkers of satiation and satiety. *American Journal of Clinical Nutrition, 79*(6), 946–961.

De Luca, R., & Botelho, D. (2019). The unconscious perception of smells as a driver of consumer responses: A framework integrating the emotion-cognition approach to scent marketing. *AMS Review*. https://doi.org/10.1007/s13162-019-00154-8

de Wijk, R., Smeets, P., Polet, I. A., Holthuysen, N., Zoon, J., & Vingerhoeds, M. (). Aroma effects on food choice task behavior and brain responses to bakery food product cues. *Food Quality and Preference, 68*, 304–314. https://doi.org/10.1016/J.FOODQUAL.2018.03.015

de Wijk, R., & Zijlstra, S. (2012). Differential effects of exposure to ambient vanilla and citrus aromas on mood, arousal and food choice. *Flavour, 1*(24). https://doi.org/10.1186/2044-7248-1-24

Dijksterhuis, G. (2016). Multisensory flavor priming. In *Multisensory flavor perception: From fundamental neuroscience through to the marketplace* (pp. 133–153). Elsevier. https://doi.org/10.1016/B978-0-08-100350-3.00007-9.

Egecioglu, E., Skibicka, K. P., Hansson, C., Alvarez-Crespo, M., Friberg, P. A., Jerlhag, E., … Dickson, S. L. (2011). Hedonic and incentive signals for body weight control. *Reviews in Endocrine and Metabolic Disorders, 12*(3), 141–151.

Ferriday, D., & Brunstrom, J. M. (2011). 'I just can't help myself': Effects of food-cue exposure in overweight and lean individuals. *International Journal of Obesity, 35*(1), 142–149. https://doi.org/10.1038/ijo.2010.117

Finlayson, G., King, N., & Blundell, J. (2008). The role of implicit wanting in relation to explicit liking and wanting for food: Implications for appetite control. *Appetite, 50*(1), 120–127.

Gaillet, M., Sulmont-Rossé, C., Issanchou, S., Chabanet, C., & Chambaron, S. (2013). Priming effects of an olfactory food cue on subsequent food-related behaviour. *Food Quality and Preference, 30*(2), 274–281. https://doi.org/10.1016/j.foodqual.2013.06.008

Gaillet-Torrent, M., Sulmont-Rossé, C., Issanchou, S., Chabanet, C., & Chambaron, S. (2014). Impact of a non-attentively perceived odour on subsequent food choices. *Appetite, 76*, 17–22. https://doi.org/10.1016/j.appet.2014.01.009

Groesz, L. M., McCoy, S., Carl, J., Saslow, L., Stewart, J., Adler, N., … Epel, E. (2012). What is eating you? Stress and the drive to eat. *Appetite, 58*(2), 717–721.

Hummel, G., Zerweck, I., Ehret, J., Salazar Winter, S., & Stroebele-Benschop, N. (2017). The influence of the arrangement of different food images on participants' attention: An experimental eye-tracking study. *Food Quality and Preference, 62*, 111–119.

Ishihara, S. (1951). *Test for colour-blindess (10th compl)*. Tokyo: Nippon Isho Shuppan Co.

Köster, E. P. (2009). Diversity in the determinants of food choice: A psychological perspective. *Food Quality and Preference, 20*(2), 70–82. https://doi.org/10.1016/J.FOODQUAL.2007.11.002

Krajbich, I., Armel, C., & Rangel, A. (2010). Visual fixations and the computation and comparison of value in simple choice. *Nature Neuroscience, 13*(10), 1292–1298. https://doi.org/10.1038/nn.2635

Landis, N. B., Welge-Luessen, A., Brämerson, A., Bende, M., Mueller, C. A., Nordin, S., … Hummel, T. (2009). "Taste strips" - A rapid, lateralized, gustatory bedside identification test based on impregnated filter papers. *Journal of Neurology, 256*, 242–248. https://doi.org/10.1007/s00415-009-0088-y

LearningExpress (Organization). (2005). 501 challenging logic and reasoning problems (2nd Editio). LearningExpress, LLC, New York.

Lenth, R. V. (2016). Least-Squares Means: The R Package **lsmeans**. *Journal of Statistical Software, 69*(1), 1–33. https://doi.org/10.18637/jss.v069.i01

Mas, M., Brindisi, M.-C., Chabanet, C., Nicklaus, S., & Chambaron, S. (2019). Weight status and attentional biases toward foods: Impact of implicit olfactory priming. *Frontiers in Psychology | Www. Frontiersin. Org, 1*, 1789. https://doi.org/10.3389/fpsyg.2019.01789

McCrickerd, K., & Forde, C. G. (2016). Sensory influences on food intake control: Moving beyond palatability. *Obesity Reviews, 17*(1), 18–29. https://doi.org/10.1111/obr.12340

Morquecho-Campos, P., de Graaf, K., & Boesveldt, S. (2020). Smelling our appetite? The influence of food odors on congruent appetite, food preferences and intake. *Food Quality and Preference, 85*, 103959.

Mors, M. R., Polet, I. A., Vingerhoeds, M. H., Perez-Cueto, F. J. A., & de Wijk, R. A. (2018). Can food choice be influenced by priming with cucumber or bread odour? Food Quality and Preference, 66(June 2017), 148–152. DOI:10.1016/j.foodqual.2018.01.019.

Mueller, C., Kallert, S., Renner, B., Stiassny, K., Temmel, A. F. P., Hummel, T., & Kobal, G. (2003). Quantitative assessment of gustatory function in a clinical context using impregnated "taste strips". *Rhinology, 41*(1), 2–6.

Oleszkiewicz, A., Schriever, V. A., Croy, I., Hähner, A., & Hummel, T. (2019). Updated Sniffin' Sticks normative data based on an extended sample of 9139 subjects. *European Archives of Oto-Rhino-Laryngology, 276*(3), 719–728. https://doi.org/10.1007/s00405-018-5248-1

Orquin, J. L., & Mueller Loose, S. (2013). Attention and choice: A review on eye movements in decision making. *Acta Psychologica, 144*(1), 190–206. https://doi.org/10.1016/j.actpsy.2013.06.003

Proserpio, C., de Graaf, C., Laureati, M., Pagliarini, E., & Boesveldt, S. (2017). Impact of ambient odors on food intake, saliva production and appetite ratings. *Physiology & Behavior, 174*, 35–41. https://doi.org/10.1016/j.physbeh.2017.02.042

Proserpio, C., Invitti, C., Boesveldt, S., Pasqualinotto, L., Laureati, M., Cattaneo, C., & Pagliarini, E. (2019). Ambient odor exposure affects food intake and sensory specific appetite in obese women. *Frontiers in Psychology, 10*, 7. https://doi.org/10.3389/fpsyg.2019.00007

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

Ramaekers, M. G., Boesveldt, S., Lakemond, C. M. M., van Boekel, M. J. S., & Luning, P. A. (2014). Odors: Appetizing or satiating? Development of appetite during odor exposure over time. *International Journal of Obesity, 38*(5), 650–656. https://doi.org/10.1038/ijo.2013.143

RIVM. (2019). NEVO online version. http://nevo-online.rivm.nl/Default.aspx.

Rozin, P, & Vollmecke, T A (1986). Food likes and dislikes. *Annual Review of Nutrition, 6*(1), 433–456.

RStudio Team. (2016). *RStudio: Integrated development environment for R*. Boston, MA: RStudio Inc.

Seo, H. S., Roidl, E., Müller, F., & Negoias, S. (2010). Odors enhance visual attention to congruent objects. *Appetite, 54*(3), 544–549. https://doi.org/10.1016/j.appet.2010.02.011

Smeets, M. A. M., & Dijksterhuis, G. (2014). Smelly primes - When olfactory primes do or do not work. *Frontiers in Psychology, 5*, 1–10. https://doi.org/10.3389/fpsyg.2014.00096

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

Tulving, E., & Schacter, D. L. (1990). Priming and human memory systems. *Science, 247*(4940), 301–306.

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

Wang, E., Cakmak, Y. O., & Peng, M. (2018). Eating with eyes – Comparing eye movements and food choices between overweight and lean individuals in a real-life buffet setting. *Appetite, 125*, 152–159. https://doi.org/10.1016/J.APPET.2018.02.003

Yau, Y. H. C., & Potenza, M. N. (2013). Stress and eating behaviors. *Minerva Endocrinologica, 38*(3), 255–267. http://www.ncbi.nlm.nih.gov/pubmed/24126546.

Zoon, H., de Graaf, C., & Boesveldt, S. (2016). Food Odours Direct Specific Appetite. Foods, 5, 12–22. DOI:10.3390/foods5010012.

Zoon, H., He, W., de Wijk, R. A., de Graaf, C., & Boesveldt, S. (2014). Food preference and intake in response to ambient odours in overweight and normal-weight females. *Physiology & Behavior, 133*, 190–196. https://doi.org/10.1016/j.physbeh.2014.05.026