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Impact of ambient odors on food intake, saliva production and appetite ratings

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HIGHLIGHTS

- Effect of ambient odor on appetite, salivation and food intake was investigated.
- A significant odor effect on food intake and salivation was found.
- Odors signaling high-energy dense products increased food intake and salivation.
- Appetite increased significantly with odor exposure and increased over time.
- Odor exposure did not induce specific appetite for congruent products.

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ABSTRACT

The aim of this study was to investigate the effect of ambient odor exposure on appetite, salivation and food intake. 32 normal-weight young women (age: 21.4 ± 5.3 year; BMI: 21.7 ± 1.9 kg/m^2) attended five test sessions in a non-satiated state. Each participant was exposed to ambient odors (chocolate, beef, melon and cucumber), in a detectable but mild concentration, and to a control condition (no-odor exposure). During each condition, at different time points, participants rated appetite for 15 food products, and saliva was collected. After approximately 30 min, *ad libitum* intake was measured providing a food (chocolate rice, high-energy dense product) that was congruent with one of the odors they were exposed to. A significant odor effect on food intake ($p = 0.034$) and salivation ($p = 0.017$) was found. Exposure to odors signaling high-energy dense products increased food intake (243.97 ± 22.84 g) compared to control condition (206.94 ± 24.93 g; $p = 0.03$). Consistently, salivation was increased significantly during chocolate and beef exposure (mean: 0.494 ± 0.050 g) compared to control condition (0.417 ± 0.05 g; $p = 0.006$). Even though odor exposure did not induce specific appetite for congruent products ($p = 0.634$), appetite scores were significantly higher during odor exposure ($p < 0.0001$) compared to the no-odor control condition and increased significantly over time ($p = 0.010$). Exposure to food odors seems to drive behavioral and physiological responses involved in eating behavior, specifically for odors and foods that are high in energy density. This could have implications for steering food intake and ultimately influencing the nutritional status of people.

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1. Introduction

Among the factors that are involved in regulating eating behavior, the sensory properties of food are important mediators for appetite, desire to eat, and actual food intake [1–3]. In particular, the olfactory modality plays a key role in our eating behavior, not only during consumption, but also before eating. In this context, studies suggest that exposure to food odors, such as the smell of pizza or warm cookies, can stimulate salivation [4–6], induce appetite [7,8] and even increase food intake, depending on participants' body mass index [5,9], impulsivity [10] and level of dietary restraint [11–13]. For example, Ramaekers et al. [8] found that food odors, such as bread and chocolate, stimulated appetite and choice for congruent foods. Similarly, in recent research, Zoon et al. [7] found that odors signaling high energy dense foods increased appetite for high energy dense products but not for low energy products, and *vice versa*. Moreover, it has been reported that subthreshold odor exposure to fruit odors guided participants towards more fruity choices in a subsequent meal [14,15]. This suggests that odors can direct appetite and food choices to foods that are signaled by the odor specifically. One explanation could be that food

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odors convey information related to anticipation of nutrients or the energy associated with consumption [16]. Indeed, through our frequent contact with olfactory food cues we learn to associate them with the nutritional consequences after ingestion and people use these cues to estimate the energy density (low/high) and taste (sweet/savory) of a food [7,17].

The sensory properties of food (*e.g.* sight, smell and taste) as well as the thought of eating [18,19] can elicit cephalic phase responses, such as salivation, gastric activity, and insulin release. These anticipatory physiological responses activate digestive and endocrine cascades which increase the efficiency of the digestion and metabolism, but also directly and indirectly regulate meal size and duration [20]. For instance, saliva production can be elicited by learned or conditioned reflexes [21] and can be stimulated in response to exposure to the sights and smells of food cues, as a preparatory response [4,22,23]. However, results from literature are somewhat inconsistent and it is unclear to what extent and specificity these salivary responses occur. Some findings support the hypothesis that salivation can be stimulated by seeing or smelling appetizing foods, as a preparatory response for food intake [24,27] while in other studies no increase in salivation from seeing or smelling an appetizing food product was reported [8,10,24–26].

Although it is plausible that food odors contribute to the regulation of food intake, and consequently energy intake, scientific evidence is scarce to support this hypothesis. Indeed, some studies showed a decrease in intake upon odor exposure [12,28], while other researchers found an increased intake [2,11] or reported no effect of odor exposure on *ad libitum* intake [29–31]. Overall, there appears to be a gap between self-report ratings of eating behavior and actual consumption. Indeed, it has been shown that the amount of food people indicate that they would like to eat is not necessarily equal to what they will consume [32–34].

Considering the rapidly increased prevalence of overweight and obesity, it is crucial to elucidate the different factors (including food odor exposure), involved in the processes leading up to actual intake. It is suggested that the modern Western food environment, which exposes individuals to copious cues of highly palatable and high energy dense foods, is driving the current obesity epidemic [35]. In order to better understand factors that may lead to overweight, it is important to gain insight into how and under what conditions normal weight/lean people are affected by these sensory food cues, such as the sight or smell of food. Ambient odor exposure could then be used to steer food intake towards healthier foods.

The aim of the current study was to investigate the effects of ambient odor exposure on behavioral and physiological measurements in normal weight individuals, in a non-satiated state. Our primary interest was to evaluate the influence of odors signaling different types of foods (high and low in energy-density, sweet and savory products) on appetite, saliva production and food intake. We hypothesized that food intake and appetite would increase upon exposure to congruent (*e.g.* exposure to chocolate odor, appetite/intake of chocolate product) *versus* incongruent odors (*e.g.* exposure to beef odor, appetite/intake of chocolate product). We further hypothesized that saliva production would increase upon exposure to food odors.

2. Material and methods

2.1. Participants

Eighty seven normal weight (BMI: 18–25 kg m^{-2}) female candidates recruited around Wageningen University were invited for a screening session in which body weight (kg) and height (m) were determined. Restraint score (1–5) was determined by using the Dutch Eating Behavior Questionnaire (DEBQ [36]). Higher scores indicate higher dietary restraint; in order to only include people with a normal eating behavior subjects that scored > 2.9 on the restraint subscale were excluded [36]. Only normosmic subjects, *i.e.* score ≥ 12 on the Sniffing Sticks 16 items odor identification test [37], that were in good general health, not using medication other than paracetamol and oral contraceptives were included. We also excluded subjects that were vegetarian or vegan, had any food allergies or intolerances, or were habitual smokers. Subjects that did not like the odor or the test meal used in the study (<40 mm on a 100 mm VAS) were excluded in order to not negatively affect physiological and behavioral responses. After the screening session, thirty-two healthy, normal weight women were selected.

To ensure that participants were unaware of the true purpose of the experiment, they were informed that the aim of this study was to investigate the effect of individual variation in saliva production and eating behavior. This study was conducted according to the guidelines laid down in the Declaration of Helsinki and all procedures involving human subjects were approved by the Medical Ethical Committee of Wageningen University. Written informed consent was obtained from all subjects and they received financial compensation for their contribution.

2.2. Olfactory stimuli

The participants were exposed to five different ambient odor conditions: beef (high energy savory; International Flavors and Fragrances, IFF, 10878095; 0.02% in demineralized water), chocolate (high energy sweet; IFF, 10810180; 5% in Propylene Glycol), melon (low energy sweet; IFF, 15025874; 20% in Propylene Glycol), cucumber (low energy savory; IFF, 73519595; 100%) and no odor. All odors were distributed in identical air-conditioned rooms (Restaurant of the Future, Wageningen, the Netherlands) using vaporizers (Zaluti, Oosterhout, The Netherlands) set to release them in a detectable but mild concentration, as determined by a pilot study.

The pilot study was carried out with four separate groups of subjects, each one consisting of 20 subjects (total n = 80), who had to indicate how intense the ambient odor was (100 mm VAS, not at all-very) and categorize the odors into low/high energy dense and sweet/savory or neutral food products. The pilot study showed that the odors were perceived as detectable but mild (chocolate: 45.20 ± 8.49; beef: 44.26 ± 7.78; melon: 43.13 ± 9.65; cucumber: 43.65 ± 14.12). Moreover, 70% of the participants categorized correctly the chocolate odor as high-energy dense sweet, 72% categorized the beef odor as high-energy dense savory, 67% categorized the melon odor as low-energy dense sweet and finally 65% of the participants categorized the cucumber odor as low-energy dense savory.

The pleasantness of the odors was evaluated during the screening sessions involving the participants of the experimental sessions (n = 32). The pleasantness ratings were analyzed through one-way ANOVA and the results showed that chocolate odor obtained significant ($F_{(3,124)} = 3.70$; $p < 0.01$) higher liking score (M = 69.40 ± 22.97) than the other odors, which were comparable to each other (beef M = 50.55 ± 28.05; cucumber M = 56.06 ± 19.60; melon M = 55.56 ± 23.49).

2.3. Procedure

Participants attended five separate test sessions on different days, between 8:30 and 16:30. Test sessions and participants were spread out evenly across the day. The participants attended each session at the same time of the day, and had at least one day wash-out period between their sessions. They were asked to refrain from eating and drinking anything but water and weak tea in the 3 h before the test session. Two participants, separated from each other by a screen, were tested in each of the rooms. The order of odor conditions was randomized but not fully balanced, since there were four time slots per day and five odor conditions per test day.

Upon arrival, only in the first session, participants started by filling out a questionnaire on impulsivity behavior (BIS-11, Barratt Impulsiveness Scale [38]) and on reward sensitivity (BIS/BAS, Behavioral Inhibition System, Behavioral Activation/Approach System [39,40]) in a non-odorous room. Further, in each session, participants filled out a questionnaire on general appetite (hunger, fullness, satiety, prospective consumption, desire to eat, and thirst), as well as appetite for fifteen specific products, all measured on 100 mm computerized visual analogue scales (VAS, not at all-very). Saliva was collected using cotton rolls placed under the tongue for 60s [5,41].

After 10 min, participants entered one of the test rooms where they were exposed to one of the ambient odor or no-odor control conditions. The participants were given instructions on a computer (EyeQuestion, Version 3.11.1, Logic8 BV) to repeat the specific appetite questionnaire (1, 8, and 15 min after entering the odorous room) and to collect saliva (3 and 10 min after entering the odorous room). After approximately 30 min of exposure, *ad libitum* food intake was measured, providing a food product (chocolate rice) that was congruent with one of the odors the subjects were exposed to. The timeline of the study procedure for each of the five sessions is reported in Fig. 1.

2.4. Measurements

2.4.1. Specific appetite ratings

After 1,8 and 15 min of odor exposure, participants filled out the appetite questionnaire, rating how much they would want to eat 15 different food products, at that moment. The 15 products, and thus the specific appetite scores, were given in a randomized order at every time point. Three products were included for each category (see also [7]): high energy sweet (HESw), high energy savory (HESa), low energy sweet (LESw), low energy savory (LESa) and three neutral food products (in terms of flavor) were added as control. All of them can be considered as snack foods in the Netherlands. HESw products included pieces of chocolate, cake and stroopwafel (a Dutch caramel syrup waffle); HESa were beef croquette, cheese cubes and crisps; LESw products were a slice of melon, an apple and strawberries; LESa products included pieces of cucumber, tomato salad and raw carrot; bread, croissants and pancake were included as neutral products.

2.4.2. Salivation

Saliva production was measured after 3 and 10 min of odor exposure, using the absorption of saliva by cotton rolls, a technique that provides a sensitive single measure of whole-mouth saliva volume [5,41]. Pre-weighed plastic bags were given to the subjects containing a single cotton roll and, at specific time points, they were instructed to place the cotton roll in their mouth under the tongue for 60 s in the most comfortable way, and to keep their tongue relaxed. Moreover, they were instructed to swallow as usual before insert the cotton roll. After this period, the participants removed the cotton roll and returned it to the plastic bag, which was then weighed a second time by the experimenter. The difference was calculated to assess amount of saliva production.

2.4.3. Food intake

Food intake (g) was measured after ~30 min of odor exposure. During the screening session, liking for two different food products (beef rice and chocolate rice), congruent with two of the odors used during the exposure, was measured. Rice was chosen as test meal since it is commonly eaten and it is easily manipulated into sweet and savory versions [42,43]. The chocolate version, that was the preferred one, was chosen for *ad libitum* intake. Participants were instructed to eat the chocolate rice as much as they wanted until they felt comfortable satiated and to consume water only after eating. The subjects received a portion of chocolate rice weighing 600 g (800 kcal; for ingredients see Table 1), an amount that allowed for *ad libitum* intake, and were unaware that it was weighed before and after the test session to determine food intake.

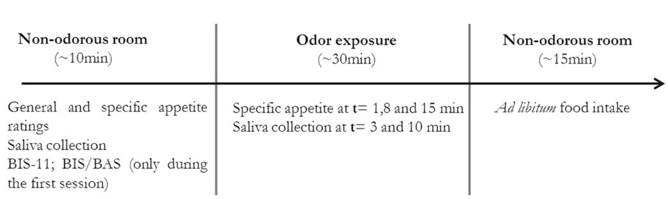

Fig. 1. Schematic timeline of study procedure for each of the five sessions.

2.5. Data analysis

All main analyses were performed following a linear mixed models effects procedure in IBM SPSS Statistics for Windows, Version 22.0 (IBMCorp., Armonk NY). A p-value of < 0.05 was considered significant.

Baseline hunger (composite score of hunger, fullness and satiety (reversed scores), prospective consumption, desire to eat scores) and thirst ratings were not different between the odor conditions, and therefore not included in subsequent analyses. Participants were added as random factor in all the analyses. To assess differences between odor categories, for all analyses, odors were also divided into high energy dense products (chocolate and beef), low energy dense products (melon and cucumber), sweet products (chocolate and melon), and savory products (beef and cucumber).

To determine the influence of odor exposure on food intake, a basic model was constructed with *ad libitum* intake of chocolate rice (g) as dependent factor, and 'odor condition' (four odors and no odor-control condition) as fixed factor. To check for possible confounding or modulating effects, separate analyses were performed by adding 'hours' (morning sessions = from 8:30 until 12:30; afternoon sessions = from 13:30 until 16:30), 'session' (the order of odor conditions), BIS11 scores, and BIS/BAS scores (impulsivity and reward sensitivity), as covariate to the model.

To determine the influence of odor exposure on saliva production, a basic model was constructed with amount of saliva (g) as dependent factor, and 'odor condition', 'time point' (saliva was measured at baseline, after 3 and 10 min of odor exposure), and their interaction, as fixed factors. The interaction was not significant and thus subsequently removed from the model. Additional analyses were performed to check for possible confounding or modulating effects, by adding 'hours' and 'session' as covariate to the model.

Appetite ratings (100 mm VAS) were analyzed by adding specific appetite scores (for all 15 products) as dependent factor, and 'odor condition', 'time point' (specific appetite scores were assessed at baseline, after 1, 8 and 15 min of odor exposure), 'product category' (the food products were categorized in: neutral products, HESa, HESw, LESa and LESw), and their interactions as fixed factors. The interactions between odor condition and product category, and between odor condition and time point were not significant, and therefore removed from the model. Additional analyses were performed to check for possible confounding or modulating effects, by adding 'hours', 'session', BIS11 scores, and BIS/BAS scores as covariate to the model.

Table 1
Ingredients to prepare 1 kg of chocolate rice.

Ingredients	Amount (g)
Rice	130
Water	379
Semi skimmed milk	304
Margarine	30
Sugar	113
Vanilla aroma	20
Cacao powder	25

3. Results

Participants' characteristics are presented in Table 2.

3.1. Food intake

There was a significant effect of odor condition on participants' food intake ($F_{(4,123)} = 2.70$; $p = 0.034$). Fig. 2 shows the *ad libitum* amount of chocolate rice eaten in the various conditions. *Post hoc* comparisons revealed that intake was significantly higher after chocolate odor exposure (mean ± SE: 245.85 ± 24.79 g) compared to no odor exposure (206.93 ± 24.93 g; p = 0.047) and to melon (193.55 ± 24.79 g; p = 0.008). Similar results were found regarding beef odor exposure (242.09 ± 24.79 g): *ad libitum* intake under this condition was higher compared to no odor exposure, albeit not significant (p = 0.073), and was significantly higher than during melon exposure (p = 0.013). Considering the covariates, only 'session' influenced the effect of odor condition on *ad libitum* intake, though the odor effect remained significant (p = 0.038): *ad libitum* intake during the first session was significantly lower ($F_{(1,122)} = 11.56$; $p = 0.001$) compared to the other four sessions, which were comparable to each other.

When categorizing the odors according to energy-density, there was a significant effect of odor category on the amount of chocolate rice eaten ($F_{(2,125)} = 4.40$; $p = 0.014$). According to *post hoc* analysis, odors signaling high energy dense food products (chocolate and beef) increased food intake (mean: 243.97 ± 22.84 g) compared to odor signaling low dense food products (melon and cucumber, mean: 207.08 ± 22.84 g; p = 0.008) and control condition (206.94 ± 24.93 g; p = 0.03). Categorizing the odors into sweet (melon and chocolate) and savory products (beef and cucumber), yielded no significant differences.

3.2. Salivation

There was a significant effect of odor condition on participants' salivation ($F_{(4,439)} = 3.05$; $p = 0.017$). Mean saliva production during the different odor conditions are reported in Fig. 3. *Post hoc* comparison revealed that saliva production was significantly higher during chocolate exposure (mean ± SE: 0.496 ± 0.052 g) compared to control condition (0.417 ± 0.052 g; p = 0.015) and to cucumber (0.417 ± 0.052 g; p = 0.014). Similar results were found regarding beef odor exposure (0.492 ± 0.052 g); saliva production under this condition was significantly higher compared to no odor exposure (p = 0.021) and to cucumber (p = 0.020). A significant effect of time point on salivation was found ($F_{(2,439)} = 7.16$; $p = 0.001$): saliva production decreased as measured over time. Considering the covariates, only 'session' influenced the effect of odor condition on saliva production, though the odor effect remained marginally significant (p = 0.061). Specifically, salivation during the first session was significantly higher ($F_{(1,438)} = 24.42$; $p < 0.0001$) compared to the other four sessions, which were comparable to each other.

When categorizing the odors according to energy-density, there was a significant effect of odor category on salivation ($F_{(2,441)} = 4.28$; $p = 0.014$). According to *post hoc* analysis, odor signaling high energy dense food products significantly increased the saliva production (0.494 ± 0.050 g) compared to no odor exposure (0.417 ± 0.052; p = 0.006) and to odor signaling low dense food products (0.447 ± 0.050 g; p = 0.041). Categorizing the odors into sweet and savory products, there were significant differences on salivation ($F_{(2,441)} = 3.19$; $p = 0.042$), showing that odor signaling sweet products significantly increased the saliva production (0.487 ± 0.050 g) compared to no odor exposure (0.417 ± 0.052; p = 0.013). No significant differences were found in salivation between odor signaling sweet and savory products (p = 0.156).

Table 2
Characteristics of study participants (data are reported as mean values ± SD).

Characteristic	Subjects (n = 32)
Age (years)	21.4 ± 5.30
BMI (kg m^{-2})	21.7 ± 1.90
BIS11	67.2 ± 5.43
BIS/BAS	
- Bis score	15.1 ± 1.99
- Bas score	25.2 ± 3.66

BIS-11, Barratt Impulsiveness Scale [38]; BIS/BAS, Behavioral Inhibition System, Behavioral Activation/Approach System [39,40].

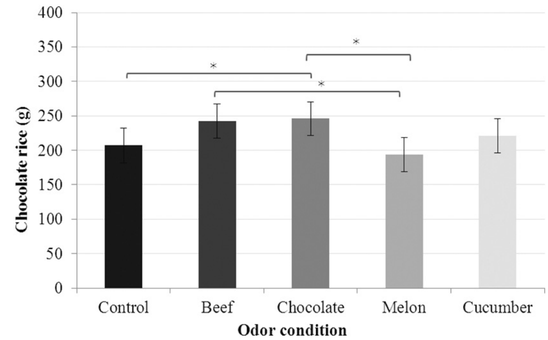

Fig. 2. Mean total amount of chocolate rice (g) eaten *ad libitum* after 30 min of odor exposure (error bars showing SE). Significant differences in intake between odor conditions are indicated by *.

3.3. Specific appetite ratings

The interaction between odor condition and product category on specific appetite ratings was not significant ($F_{(16,9481)} = 0.84$; $p = 0.634$), indicating no sensory specific appetite. However, there was a significant effect of odor condition on overall appetite scores ($F_{(4,9481)} = 5.08$; $p < 0.0001$), as well as of time point ($F_{(3,9481)} = 3.77$; $p = 0.010$). Appetite scores were higher during all odor conditions, regardless of the specific odor, compared to the no-odor control condition (Fig. 4), and increased during odor exposure. Considering the covariates, only 'session' had a significant impact, though the odor effect remained significant (p = 0.025). In particular, during the first session the appetite scores were higher ($F_{(1,9480)} = 15.45$; $p < 0.0001$) compared to the other sessions, which were comparable to each other.

4. Discussion

The objective of the present study was to investigate food intake, saliva production and appetite in response to ambient odors signaling different food products (high and low in energy-density, sweet and savory).

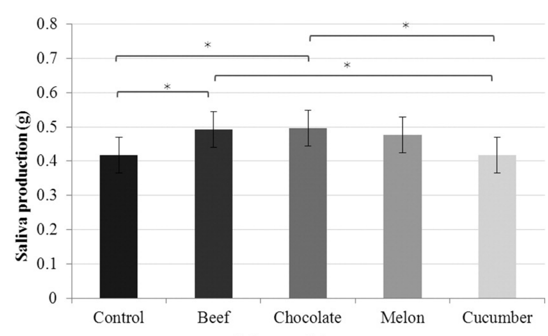

Fig. 3. Mean saliva production (g; averaged over the time points) and error bars showing SE during the different odor conditions. Significant differences between odor condition are indicated by *.

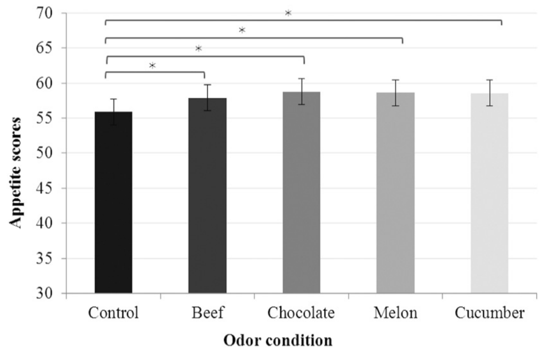

Fig. 4. Mean appetite ratings (of all specific products, rated on 100 mm VAS) and error bars showing SE, averaged over the time points, during the different odor conditions. Significant differences between odor condition are indicated by *.

Our findings are one of the first to systematically reveal an effect of ambient odor exposure on actual food intake. In particular, a significant increase of the amount of chocolate rice eaten upon chocolate and beef odor exposure was found. It could be argued that this effect is driven by liking of the odors rather than energy-density signaling (*i.e.* that odors representing high energy dense foods are more liked than low energy foods/odors). However, odors and foods were carefully selected and similar in liking to prevent this possible confound. Given that beef, melon and cucumber odors had similar liking ratings (and only chocolate odor was rated higher), it is likely that the increasing food intake upon chocolate and beef odor exposure can be attributed to the fact that both these odors signal high energy dense food products, similar to the chocolate rice. In fact, the total eaten amount was more affected during high energy odor condition compared to the low energy one. Unexpectedly, when categorizing the odor conditions according to taste category (sweet/savory), no significant differences were found on intake. Indeed, the odors signaling sweet food products did not increase food intake of chocolate rice compared to savory odors. It is possible that the chocolate rice elicited mixed associations in our participants, as rice is often associated with a savory meal while chocolate is typically linked to sweet meals.

Even if previous studies, using both visual and olfactory cues, similarly demonstrated an increase in food intake [1,44], these results have been inconsistent in the literature [10,12,13]. Indeed, some findings showed a negative odor effect on intake [12,28], while other researchers found a positive effect [2,11] and other results reported no effect of odor exposure on *ad libitum* intake [29–31]. Actually, there appears to be a gap between self-report ratings of eating behavior and actual consumption. Indeed, Ferriday et al. [5], involving lean and overweight subjects, demonstrated that the exposure to the sight and smell of pizza increased participants' desire to eat but not the actual food intake.

The difference between these studies could lie in the different concentrations of the odors and thus differences in awareness of the subjects towards the food cues. Accordingly to this hypothesis, in a recent study in which ambient odors were presented at clearly noticeable intensities, food consumption was not affected by odor exposure [30].

It is important to consider that in our study, using odors in a detectable but mild concentration, the results for the 'implicit' measurement (food intake, unknowingly measured and salivation) were greater and more specific than for the explicit measure (specific appetite ratings). This is in line with evidence that food choices and eating behavior, are driven mainly by non-conscious processes [15,45,46]. In particular, it has been proposed that odors are better able to influence behavior outside of awareness than in conditions in which it is possible to reliably identify the odor [47].

In the current study, we could not demonstrate a sensory-specific appetite effect of odor exposure. This was an unexpected result considering that various studies have now reliably shown that odors [7,8] and both odor and visual cues [5,11] can specifically induce appetite for the cued foods. However, our results show that appetite scores were higher during odor exposure compared to the no-odor control condition, regardless of the specific odors, and increased over time, demonstrating a clear effect of odor exposure.

This study revealed not only effects of ambient odor exposure on behavioral outcomes but also on physiological measurements. A significant odor effect on saliva production over time was found. Beef and chocolate odors, which increased the *ad libitum* intake, also enhanced salivation. Though for many years it has been claimed that the mere sight of food is capable of "*making the mouth water*" [48,49], researchers suggested that not only sight, but also smell could affect salivary flow rates [23,27,50]. However, conflicting results have been reported regarding the ability of odors to induce salivation. Some findings support the hypothesis that salivation can be stimulated by seeing or smelling appetizing foods, as a preparatory response for food intake [5,22–24, 48–50], while it should be noted that in other studies no increase in salivation from seeing or smelling an appetizing food product was reported [8,10,25,26,51]. The lack of salivary increase in these studies may be due to small sample sizes [21] or measurement of inappropriate salivary glands. For example, Lee and Linden [52] showed that exposure to food odors, such as tomato, vanilla, peppermint, chocolate, lemon, and beef elicited greater salivation in some salivary glands (the submandibular) but not others (the parotid). Differences between studies could be due also to the use of different methods to measure the salivation (*e.g.* counting swallows, or spitting), to the measurement of the whole mouth saliva instead of salivation from specific glands, or the time points used to collect the saliva. Moreover, our results showed that saliva production decreased over time. This is in line with previous research demonstrating that after prolonged exposure to food cues, people get used to these cues, leading to a decrease in salivary response [53]. In addition, ongoing salivary flow may have been affected by inserting the first cotton roll, and absorbing all saliva present in the mouth most of itself; or, participants might have been influenced by the procedure and felt uncomfortable using the cotton rolls. It is possible for future research to examine salivation using other approaches such as counting swallows and spitting method [54].

Unlike previous research, in which high impulsive individuals or participants who are more reward sensitive had more difficulties resisting appetizing foods, leading to a higher intake [55–58], in the present study, no significant effects of personality traits, such as impulsivity or reward sensitivity, were found on food intake. Perhaps our research sample did not include participants with a wide-enough range of impulsiveness and reward sensitivity to detect a relation with food intake.

For all our outcome measures (intake, saliva, appetite) we saw an order effect of odor condition that might have been caused by familiarization with the test setup or food product. It could be possible to hypothesize that the participants maybe attempting to control their intake more on the first session compared to subsequent sessions. This can be solved by adding a practice session to future studies. Also, this study focused exclusively on female university students, restricting the generalizability of the current findings. Considering that odors are primary triggers of a cascade of events that may ultimately lead to food intake, as future prospective, it could be interesting to involve also overweight or restrained participants in order to investigate the possibility to steer food intake away from high energy unhealthy foods, towards healthier choices. This could have important implications for reducing overweight.

5. Conclusion

In conclusion, in our "obesogenic" environment it is important to gain insight into how and under what conditions people's behavioral and physiological responses are affected by tempting, environmental food cues. We here demonstrate that exposure to odors signaling energy-dense foods, in a detectable but mild concentration, affected food intake and saliva production in a congruent way, increasing the consumption of a high-calorie product. These results suggest that exposure to food odors increases intake for congruent products in terms of energy density but not taste. The ability of odors to specifically influence the amount of food ingested, and therefore the amount of energy assimilated by individuals, could have important consequences in the context of the reduction and prevention of obesity. Future studies should be carried out in order to verify the promising possibility to increase intake of low rather than high-energy dense, healthier foods by means of congruent odor exposure. If true, odor exposure could be a potentially useful instrument both in preventing overeating and to help malnourished individuals at risk for underweight.

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The authors declare no conflict of interest.

Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.physbeh.2017.02.042.

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