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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.

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