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Influence of olfactory dysfunction on the perception of food

Y. Zang[1,4] · P. Han[2] · S. Burghardt[1] · A. Knaapila[3] · V. Schriever[1] · T. Hummel[1]

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Abstract

Purpose Eating-related problems are among the most frequent issues in olfactory impairment, causing a noticeable loss of quality of life for some of the affected persons. To what extent olfactory dysfunction impacts on the sensory perception of food is less explored. The aim of the present study was to examine the impact of olfactory dysfunction on the perception of food aromas, as well as the perception of the "basic tastes" salty, sour, sweet, and bitter.

Methods Eighty-nine participants were recruited for the prospective study. Group 1 consisted of thoroughly examined patients with olfactory dysfunction ($n = 48$, mean age = 60.0 years), group 2 consisted of people with normal olfactory function ($n = 41$, mean age = 50.4 years). First, olfactory and gustatory functions were assessed for all participants with the help of the "Sniffin'Sticks" battery and the "taste strips" test. Second, food odors were rated for their pleasantness, intensity, familiarity and desirability. Last, real food items were tasted orally and the intensity for basic taste qualities (sweet, bitter, salty, and sour) and pleasantness was rated. In addition, salivation was measured following exposure to the food odors.

Results In comparison to controls, patients rated orthonasal food odors as less pleasant, intense, familiar, and less appetizing. "Taste strip" scores were significantly lower in patients ($M = 9.56$, SD = 2.76) as compared to controls ($M = 10.88$, SD = 1.89). In addition, ratings of food liking for chocolate and peanut were lower in patients compared to controls (chocolate: patients—$M = 6.85$, SD = 2.09, controls—$M = 7.90$, SD = 1.53; peanut: patients—$M = 4.88$, SD = 2.20, controls—$M = 6.80$, SD = 2.33). No significant differences were found regarding the comparison of the salivary flow rate in controls ($M = 0.52$ g/min, SD = 0.19) and patients ($M = 0.50$ SD = 0.17).

Conclusions Changes in the perception of odors may change the perception of food with specific effects on food liking. Olfactory dysfunction affects gustatory function, indicating the central-nervous interaction between taste and smell. Still, olfactory dysfunction did not appear to affect patients' salivary flow.

Keywords Olfactory dysfunction · Smell · Eating · Taste · Flavor

Introduction

Odors play an important role in the perception of foods. Consequently olfactory dysfunction is likely to affect eating behavior. In fact, smell or taste disorders have a significant impact on the quality of daily life, including the change of dietary behaviors [1, 2]. Eating can be divided into two major phases, anticipation (seeing the food items and smelling the food aroma orthonasally) and consumption (eating the food which engages retronasal olfactory perception) [3]. It is a trivial experience how the taste of food changes when we have a cold, thus providing anecdotal support for the importance of olfactory input to the enjoyment of food and drink [4]. Although some studies have addressed the alterations of dietary behaviors in people with olfactory loss [5-7], relatively little is known about the perception of actual foods

Y. Zang and P. Han equal contributions.

✉ T. Hummel
thummel@mail.zih.tu-dresden.de

1 Interdisciplinary Center Smell and Taste, Department of Otorhinolaryngology, Medical Faculty Carl Gustav Carus, TU Dresden, Fetscherstrasse 74, 01307 Dresden, Germany

2 Faculty of Psychology, Southwest University, Chongqing, China

3 Department of Pedriatric Medicine, Faculty of Agriculture and Forestry Common Matters, Helsinki, Finland

4 Department of Otorhinolaryngology, The Affiliated Hospital XUZHOU Medical University, Xuzhou, China

in this group. Hence, the current study was designed to study orthonasal and retronasal food odor perception as well as the taste of foods using foods familiar from real life. As an indirect measure of the attractiveness of foods we also investigated salivation [8, 9]. It was hypothesized (1) that patients, when compared to controls, would exhibit decreased salivation in response to food-related odors, but not for odors that are non-food-related and (2) that patients with olfactory dysfunction rate food odor as less pleasant than controls.

Materials and methods

Subjects

Forty-eight patients with olfactory dysfunction (30 women, 18 men) were included in this prospective study. They were referred to the Smell and Taste Outpatients Clinic at the University Hospital of Dresden because of their smell and taste problems. Forty-one healthy controls (28 women, 13 men) with normal olfactory function were recruited by advertisement in the Dresden area. Following a structured history (including questions for age, sex, BMI, hunger level [scale ranging from "no hunger" to "very hungry"], smoking behavior [yes/no], alcohol consumption [yes/no]) (Table 1). All participants received a detailed otorhinolaryngological examination including nasal endoscopy. Olfactory functions were assessed using the "Sniffin' Sticks" battery [10]. Suprathreshold testing involved assessment of the patient's perception of taste intensities at levels above threshold, this was done separately for the 4 "basic tastes" (salty, sour, sweet or bitter) using magnitude matching [11]. After oral and verbal explanations of aims and potential risks of the study, participants provided written informed consent. The periods of recruitment and data collection were from July 2017 to December 2017.

Food item selection

Four food items were chosen for the current study based on their predominant taste or flavour qualities: dark chocolate (bitter), lemon curd (sour), peanut butter (salty) and caramel (sweet), they are common in everyday life and people are familiar with their taste. All food items were in semi-solid form to minimize the influence of texture on flavour perception [12]. Food items were purchased from local supermarkets. They were served at room temperature. All foods were of similar pleasantness, and participants were familiar with all of them. For orthonasal odor perception, 5 g of each food was placed in a 50 ml brown bottle with a 5 cm diameter round opening. A non-food odor (PEA, rose-like) at a concentration of 4% (in propylene glycol) was included as control odor which is not food-related. For

Table 1 Main characteristics of the participants (mean values, standard deviations) separately for patients and controls plus results from statistical comparisons between the two groups

	Patients ($n=48$)		Controls ($n=41$)		p value
	Mean	SD	Mean	SD	
Age (years)	60.85	13.87	50.39	11.24	0.230
BMI	25.81	4.65	25.60	4.01	0.494
Hunger	5.19	1.65	4.02	2.01	0.001
Appetite	3.85	2.49	4.00	2.36	0.755
TDI score	18.65	6.21	34.49	2.45	0.001
Taste strips					
Salty	2.63	1.31	3.02	0.99	0.201
Sweet	3.06	1.12	3.32	0.88	0.348
Sour	0.94	0.91	1.27	0.92	0.079
Bitter	3.00	0.71	3.41	0.74	0.004
Total score	9.63	2.67	11.02	1.81	0.011
Salivation in relation to smelling					
Baseline	7.11	0.38	7.13	0.51	0.693
Average salivation after smelling	7.08	0.35	7.10	0.39	0.869
Change after PEA	−0.05	0.36	−0.08	0.40	0.723
Change chocolate	−0.04	0.37	−0.06	0.34	0.325
Change peanut	−0.05	0.28	−0.01	0.38	0.427
Change lemon	−0.04	0.35	−0.01	0.38	0.537
Change caramel	−0.01	0.36	−0.05	0.42	0.663
Ratings of odors Pleasantness					
PEA	5.31	2.06	6.76	1.80	0.001
Chocolate	5.19	1.45	6.27	2.43	0.002
Peanut	5.04	1.92	7.07	2.09	0.001
Lemon	4.77	1.40	5.05	1.90	0.588
Caramel	5.63	1.10	6.32	1.65	0.042
Intensity					
PEA	4.42	2.74	7.22	1.67	0.001
Chocolate	3.85	2.32	6.63	1.65	0.001
Peanut	4.63	2.43	7.59	1.53	0.001
Lemon	3.67	2.21	5.76	1.85	0.025
Caramel	3.08	2.16	5.17	2.26	0.001
Familiarity					
PEA	3.77	2.87	6.37	2.29	0.001
Chocolate	3.69	2.56	6.17	2.50	0.001
Peanut	4.42	2.73	7.80	1.75	0.001
Lemon	3.48	2.67	5.93	2.64	0.001
Caramel	3.10	2.45	5.32	2.87	0.001
Appetite					
PEA	2.25	1.94	2.54	1.98	0.249
Chocolate	2.96	2.56	4.44	2.50	0.004
Peanut	2.71	2.20	5.49	2.65	0.001
Lemon	2.35	1.96	3.44	2.31	0.001
Caramel	2.71	2.11	3.32	2.46	0.169

Table 1 (continued)

	Patients ($n=48$)		Controls ($n=41$)		p value
	Mean	SD	Mean	SD	
Ratings after eating					
Liking					
Chocolate	6.85	2.09	7.90	1.53	0.005
Peanut	4.88	2.20	6.80	2.33	0.001
Lemon	6.75	2.05	6.80	1.94	0.933
Caramel	6.90	2.21	7.83	1.69	0.031
Overall intensity					
Chocolate	5.50	1.38	5.83	1.39	0.263
Peanut	5.25	2.11	5.88	1.38	0.160
Lemon	5.71	1.56	6.54	1.52	0.025
Caramel	5.42	1.62	6.05	1.47	0.097
Sweetness					
Chocolate	4.31	2.11	5.61	2.17	0.008
Peanut	2.73	1.95	4.05	2.50	0.012
Lemon	5.13	2.61	6.29	2.25	0.037
Caramel	6.85	2.11	8.05	1.16	0.008
Saltiness					
Chocolate	1.25	1.00	1.41	1.18	0.395
Peanut	3.21	2.20	4.68	2.24	0.003
Lemon	1.23	1.15	1.20	0.46	0.099
Caramel	1.38	0.94	1.24	0.83	0.413
Sourness					
Chocolate	1.85	1.74	1.76	1.70	0.624
Peanut	1.35	1.33	1.24	0.83	0.906
Lemon	4.15	2.32	5.41	2.36	0.013
Caramel	1.17	0.48	1.39	1.24	0.884
Bitterness					
Chocolate	4.06	2.44	4.51	2.68	0.408
Peanut	2.08	1.77	1.83	1.46	0.732
Lemon	1.60	1.36	1.76	1.68	0.648
Caramel	1.08	0.40	1.15	0.42	0.404
Food liking					
Sweet	6.75	2.30	7.07	2.27	0.503
Salty	4.81	2.69	5.73	2.59	0.105
Sour	5.25	2.12	4.85	2.48	0.386
Bitter	2.71	1.62	3.20	2.45	0.752
Frequency of eating food tasting like					
Sweet	2.98	1.14	3.76	1.36	0.003
Salty	2.56	1.22	3.12	1.36	0.049
Sour	2.35	1.06	2.34	0.94	0.986
Bitter	1.52	0.87	1.73	0.87	0.160

retronasal flavor perception, subjects were asked to taste 1/3 of a teaspoon (approximately 1 g) of each food item; they chewed on it and swallowed it.

Procedures

All measurements were performed by the same experimenter (SB). Following enrollment in the study and clinical examinations subjects rated their hunger state using a 100-mm visual analogue scale (left hand end: no hunger; right hand end: very hungry). After the recording of a structured history, olfactory and gustatory functions were assessed using the "Sniffin' Sticks" battery [10] and the "taste strips" test [13], respectively. The "Sniffin' Sticks" test comprises three subtests: (A) odor threshold for phenyl ethyl alcohol (PEA; single staircase, 3-alternative-forced-choice task, 3-AFC), (B) odor discrimination (16 triplets of odors, 3-AFC), and (C) odor identification (16 common odors, multiple AFC from four verbal descriptors per odor). First, the taste strips were placed on the middle of the anterior tongue. After having closed the mouth, based on a 4-AFC test, subjects then had to select the taste they perceived (sweet, sour, salty, bitter). After that, the resting-state saliva flowrate was measured using Salivettes® (Sarstedt, Nümbrecht, Germany) by putting a 4 cm long, 1 cm diameter cotton roll into the cheek pouch for 45 s [14].

Orthonasal odor presentation and salivation

Food items were presented in brown glass jars. The experimenter held the bottle mouth approximately 3 cm beneath the nostrils. The participants who were asked to cover their eyes had to breathe normally through their nose to smell the odors. Participants only smelled each item once. They put the Salivettes (weight of empty tubes 6.59 g) into their mouth, smelled the odor for 45 s and afterwards were asked to answer the related questions about the odor, while they had their 1 min break. Participants used 9-point scales to rate pleasantness, intensity, familiarity and the degree to which the odors were found to be appetizing ("appetite"). Scales ranged from very unpleasant to very pleasant; no odor to very strong odor; not familiar at all to very familiar; not appetitive at all to very strong appetitive (all scales from 1 to 9).

Retronasal odor presentation, taste perception, and eating habit

Following the smelling of the odors, participants were asked to taste the food items. Using disposable plastic spoons the experimenter placed approximately 1 g of each of the four foods in the participants' mouth, then they were asked to swish the foods in the mouth for about 10 s before they evaluated the foods. Participants rated the intensity of the basic taste qualities (sweetness, sourness, bitterness, and saltiness) for each of the four foods using nine-point scales ranging from no intensity to extremely strong intensity. During the

1 min breaks between the four samples subjects rinsed their mouths using tap water ad libitum. The order of presentation of both, odors and flavors was randomized across participants. At the end of the session participants used nine-point scales to rate how much they like to eat foods with sweet, salty, sour, and bitter tastes [scales ranging from not at all to very much (1–9)] and how often, on average, they actually ate foods with sweet, salty, sour, and bitter tastes during their daily life (scales ranging from 0 to 5: 1–2 times per month or less frequently, once per week, 2–4 times per week, once a day, twice per day or more often).

Statistical analysis

The Statistical Package for the Social Sciences (SPSS vs. 25.0; International Business Machines Corporation, New York, NY, USA) was used for data analyses. Normal distribution of data was checked with the Kolmogorov–Smirnov test. Accordingly, due to the non-normal distribution most of the data were analyzed using the Mann–Whitney test [MW-test], except for age and BMI which were analyzed with a *t* test. The Chi-square test was used for comparisons in terms of sex distribution, smoking behavior or alcohol use. To account for multiple testing a significance level of $p < 0.01$ was chosen.

Results

Characteristics of participants

*T*he two groups, controls and patients, were not significantly different in terms of age, sex distribution, BMI, smoking behavior and alcohol use (patients, $n = 48$; BMI $M = 25.8$ kg/m^2, SD = 4.7; age $M = 60.9$ years, SD = 13.9; controls, $n = 41$; BMI M = 25.6 kg/m^2, SD = 4.0; age $M = 50.4$ years, SD = 11.2; BMI *t* test: $p = 0.49$; age *t* test $p = 0.23$; sex χ^2-test: $p = 0.66$; smoking behavior: Cχ^2test $p = 1.00$; alcohol use χ^2test $p = 0.12$). However, patients were more hungry than healthy controls (MW-test $p = 0.001$). According to inclusion criteria, patients scored lower than controls on the Sniffin' Sticks test (*t* test $t = 15.3$, $p < 0.001$).

Orthonasal odor perception

In comparison to controls, patients rated the food and non-food odors as less intense, less pleasant, less familiar, and less appetitive (MW-test: $p < 0.01$) (Fig. 1). Notable exceptions were the pleasantness and intensity ratings of lemon (MW-test: $p > 0.02$) and the appetitiveness of PEA and caramel (MW-test: $p > 0.16$) where no differences were found between the two groups.

Retronasal flavor and taste perception

Patients rated chocolate and caramel to be less sweet (MW-test: $p < 0.001$), peanut was rated as less salty (MW-test: $p = 0.003$). No significant differences were present for all other taste and flavor ratings. Ratings of overall intensity of food odors were not significantly different between the two groups. In addition, also in terms of liking there was no significant difference between the two groups.

Taste functions

The taste strip scores tended to differ between the two groups with patients scoring lower (MW-test: $p = 0.011$). When looking at separate scores for the four tastes a significant difference emerged only for bitter (MW-test: $p = 0.004$). Here it has to be kept in mind that patients presented themselves because of smell disorders, and all of the participants indicated that their sense of taste was normal before they received the test.

Salivary flow

Salivary flow was not significantly different for both resting and induced salivary flow conditions (averaged across results for all odors), for either patients or controls. In addition, there were no significant differences in changes in salivary flow between patients with olfactory dysfunction and controls.

Eating habits

There was no significant difference between patients and controls regarding the liking of all food tastes. However, a significant difference was present in the frequency of eating, with patients indicating to eat sweet foods (MW-test: $p = 0.003$) at a lower frequency than controls (Fig. 2).

Discussion

Major findings of the current study were (1) patients rated odors and foods as less intense and less pleasant (2) gustatory function was decreased in patients (3) flavor-induced salivary flows were not significantly different between the two groups, and (4) ratings of food liking were not significantly different between the two groups.

Effect of olfactory dysfunction on orthonasal and retronasal odor/flavor perception

In comparison to controls, with very few exceptions patients rated the food-related and non-food-related odors (PEA) as

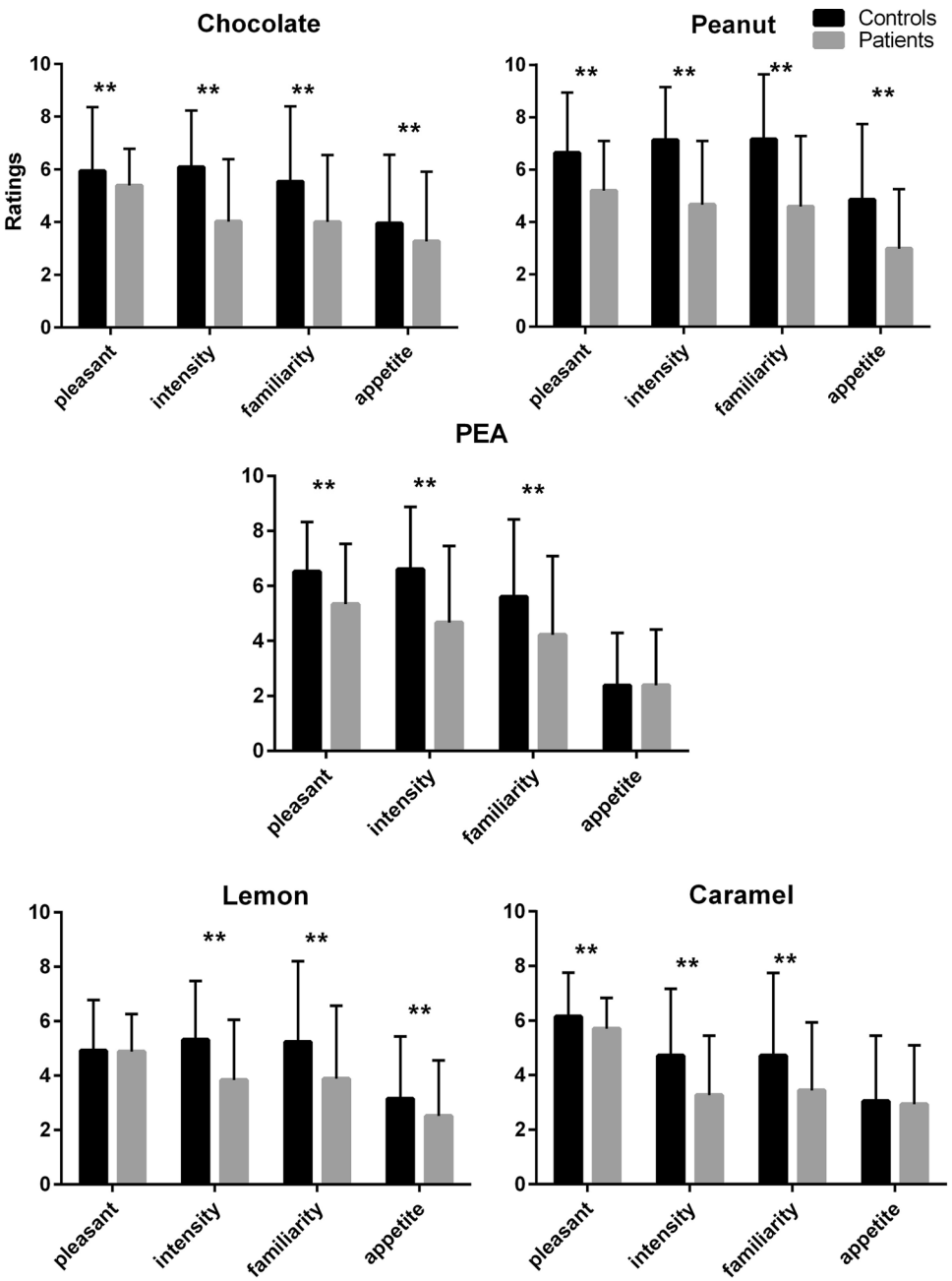

Fig. 1 Rating of pleasantness, intensity, familiarity, and "appetitiveness" of orthonasally presented odors (mean, and standard deviations). **Means significant difference

less pleasant, intense, familiar, and appetitive. However, the two groups did not differ in terms of their general food preferences. The observed differences were largely related to changes in olfactory function [15] which are associated with reduced quality of life [16].

Effect of olfactory dysfunction on gustatory function

Patients exhibited decreased scores on the taste-strips test, although the decrease was not very pronounced. This confirms previous research [17, 18]. That a decrease of the sense of smell is associated with a decline in gustatory function may be due to the interaction between gustatory, olfactory and trigeminal perception [19]. In fact, there is a spatial overlap between gustatory, olfactory, and oral somatosensory representation in the mid-dorsal insula [20]. The interactions between gustatory, olfactory and oral somatosensory functions may be a reason for the decrease in gustatory function when olfactory function fails. On a clinical level, the current results indicate that it makes sense to examine gustatory function in patients with olfactory dysfunction.

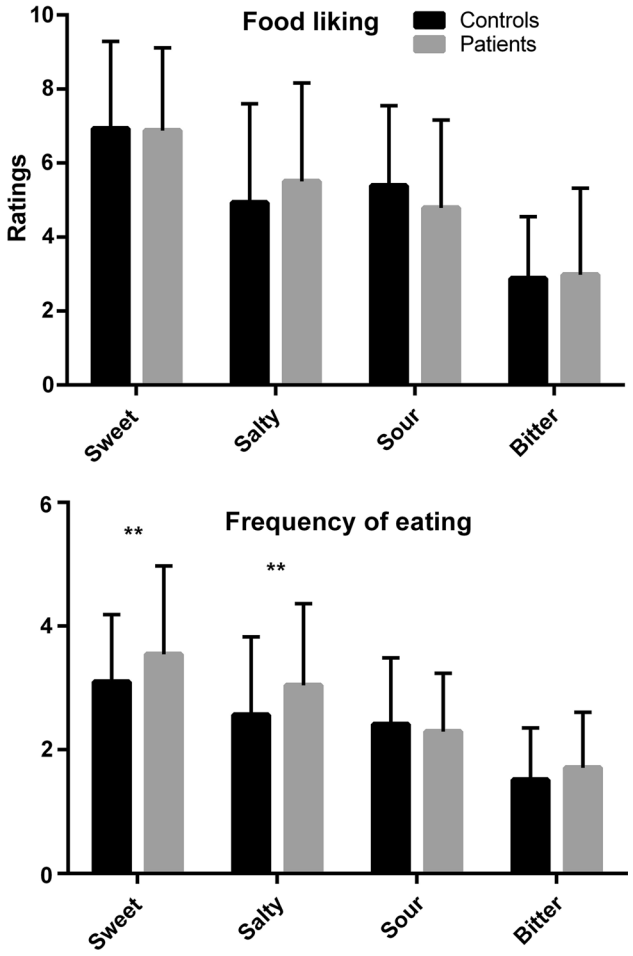

Fig. 2 Eating habits between control and patient groups in food liking and eating frequency. **Means significant difference

Effect of olfactory dysfunction on the saliva flow rate

In the current sample salivation was not significantly different between the two groups, and flavors had no major effect on salivation. These results argue against our initial hypothesis that olfactory dysfunction would be accompanied by a decrease of stimulated salivation. Our results obtained in patients are also inconsistent with other research indicating that food-related odors induce a strong increase in salivation rate [21]. Conflicting results have been reported regarding the ability of odors to induce salivation. Some findings support the hypothesis that salivation can be stimulated by smelling appetizing foods while others found no change in salivation from smelling an appetizing food product [8, 22]. One possible explanation might be the choice of food odors used in the current study which may not have been appetizing enough [14]. Another possible reason for the null results seen in the current study is that multiple measurements using cotton pads may have influenced salivation so that more variation may have occurred. Future research should examine salivation using different methodological approaches [23].

Effect of olfactory dysfunction on eating habits

Most people who seek treatment for olfactory disorders spontaneously report that food is less flavorful and less enjoyable and that their disorder changes their eating and cooking habits [24]. In this study, when compared to the control group, patients showed no significant difference with regard to ratings of food liking. This indicates that olfactory function is not the most important factor to influence dietary behavior. However, the change in the rated decrease of the frequency of eating sweet foods in patients seems to be a consequence of the loss of flavor perception, another study showed patients used or tended to use more sugar, ketchup, mayonnaise, and sour cream, and this may result from compensation mechanisms: adding sugar, ketchup, or mayonnaise may be an attempt to (1) restore some lost flavor and (2) increase palatability [25].The results may both indicate that olfactory dysfunction can influence people's eating habits. Still, it does not seem to result in a change of BMI.

Study limitations

The current study investigated the impact of olfactory dysfunction on sensory perception of food using real food items in a laboratory environment. Several limitations need to be addressed: first, although the food items were controlled for their texture and taste quality, they were all processed foods containing additives that may introduce other tastes/smells. This may have limited the power for detecting potential differences in the perception of tastes between patients and controls. Further, the overall sweet nature of the foods used may have specifically limited the detection of bitterness and sourness. In other words, the selected foods may not have fully represented the tastes they were selected to represent. Second, there was a significant difference between the two groups in terms of the hunger ratings which were higher in patients. However, one can assume that increased hunger ratings should increase olfactory and gustatory sensitivity [26]—which actually appeared to be the other way around in the current study. Accordingly, it may be hypothesized that the current results are a conservative estimate of the degree of differences between the two groups.

Conclusion

In conclusion, the current results emphasize that orthonasal olfactory dysfunction affects the perception of foods. The additional decrease in gustatory sensitivity points at

olfactory–gustatory interactions. Olfactory dysfunction appears to impact on eating habits, although olfactory dysfunction did not affect the patients' salivary flow rate.

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Compliance with ethical standards

Conflict of interest This research received financial support by the Deutsche Forschungsgemeinschaft to TH (DFG HU411/18–1). All other authors declare that they have no conflict of interest.

Research involving human participants All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. The study was approved by the Ethics committee of the Medical Faculty of the Technical University of Dresden(EK441102016). This article does not contain any studies with animals performed by any of the authors.

Informed consent Informed consent was obtained from all individual participants included in the study.

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