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ORIGINAL RESEARCH

Olfactory Capabilities Towards Food and Non-food Odours in Men and Women of Various Weight Statuses

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Abstract

Introduction Olfaction is a sense that is closely linked to food intake and food choices in humans, but its relationship with obesity remains equivocal in the scientific literature: overall olfactory capacities seem poorer in obesity compared to normal weight, but some authors observed that individuals with obesity might have a heightened sensitivity to food odours. Our objective was to evaluate olfactory capabilities for food and non-food odours.

Methods The European Test for Olfactory Capabilities (ETOC) was used. This test measures suprathreshold olfactory detection and identification capabilities. One hundred twenty-four men and women were tested, of whom 41 individuals with normal-weight, 45 individuals with overweight, and 38 individuals with obesity.

Results Contrary to the major current in the literature, no differences between the three weight status groups were found in either detection or identification capabilities, for food as well as for non-food odours. Age decreased detection score while being male decreased identification score. A trend for better identification of non-food odours was found for overweight and obesity vs. normal-weight.

Conclusion We encourage further research to distinguish food and non-food odours in olfactory measurements related to weight status in order to replicate our findings on a larger set of odours.

Implication Future research should also focus on sensitivity to food odours by estimating detection thresholds and to control for confounding variables such as hormonal status, as well as individual liking of the odours.

Keywords Food · Food odours · Obesity · Olfaction · Overweight

Introduction

Olfaction is a remarkable sense that is decisive for food behaviours. Distally, it enables the localisation of foods and thus orients food choices, while proximally, it allows flavour perception and contributes to the detection of food-related properties (such as taste and nutrients, Djordjevic et al. 2004; Stevenson 2010; Thomas-Danguin et al. 2016; Boesveldt and de Graaf 2017). Overall olfactory capacities can be described in terms of detection and identification. Detection is the ability to detect odorants and is a part of the olfactory sensitivity (Sorokowski et al. 2019). For a given odorant, different detection measures can be performed using different concentrations. On the one hand, detection and recognition thresholds are fine measures of absolute sensitivity reflected by the lowest concentration of a certain odorant that is respectively detected and recognized by the individual. To be reliable, those tasks necessitate testing a large set of odorant concentrations to find the proper concentration for each individual of the panel. On the other hand, suprathreshold detection techniques use a unique sufficiently high concentration of the odorant to be detected by healthy participants and allow to categorize participants into smellers and non-smellers (for more details on both techniques, see Doty and Laing 2015; Doty 2018). Identification is the ability to correctly name a smell, and it relies more on cognitive aspects, such as verbal abilities (Larsson et al. 2004) and habits (Nováková et al. 2014b). It is of particular interest to study

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olfactory capacities in obesity research for several reasons. First, according to incentive-sensitization models of eating behaviour (Robinson and Berridge 1993; Appelhans 2009; Berridge 2009; Berridge et al. 2010; Joyner et al. 2017), individuals with obesity might have an increased sensitivity to stimuli that are related to reward, namely palatable foods cues, such as the sight or smell of pleasant foods. Second, exposure to food cues might increase appetite for foods that are congruent with the cue (Ramaekers et al. 2014; Zoon et al. 2016). This effect has been widely studied for taste and sight, but more rarely for smell (Peng et al. 2019). Some previous studies indicated a modification in attentional biases towards food pictures (Mas et al. 2019) and reaction times (Mas et al. 2020) in individuals with obesity exposed to food odours at low concentrations. In line with incentive-sensitization theory, the link between food and reward might be heightened in individuals with obesity, and they might consequently be more prone to detect and identify food-related odours (especially sweet-congruent odours).

Several studies have found that the sense of smell of individuals with obesity was different from the sense of smell of individuals with normal weight. On the one hand, results indicating decreased olfactory capabilities in individuals of higher weight status have been observed. Some studies showed that women with obesity have a poorer sense of smell in terms of detection (lower detection threshold, Fernández-Aranda et al. 2016; Fernandez-Garcia et al. 2017) and identification (Richardson et al. 2004; Fernández-Aranda et al. 2016; Fernandez-Garcia et al. 2017) of odours compared to women with normal weight status. Detection thresholds (the lowest concentration of a certain odour compound that is perceivable by the individual) were found to be higher in individuals with overweight and obesity than in individuals with normal weight status, indicating a lower sensitivity to odours (Skrandies and Zschieschang 2015; Fernández-Aranda et al. 2016). Moreover, studies on mice models showed that mice submitted to an obesogenic diet had a decreased olfactory discrimination ability and a reduced number of olfactory sensory neurons, even after weight loss (Thiebaud et al. 2014). Decreased olfactory capacities could thus be linked with the alteration of eating behaviour and food intake in humans (Aschenbrenner et al. 2008). This link between body mass index (BMI) and olfaction could contribute to increased consumption of palatable food in individuals with higher weight status in order to reach a pleasant sensation that is comparable to the sensation of individuals with normal olfactory capacities (Boesveldt 2017).

On the other hand, some studies seem to indicate that the olfactory differences between normal weight and individual with higher weight statuses might be linked with food intake. A study showed that individuals with obesity seem to have lower olfactory thresholds to certain food odours (chocolate, Stafford and Whittle 2015), indicating a higher sensitivity to those odours. Higher sensitivity to specific food odours might make individuals with obesity lean towards unhealthy food consumption, but those results need to be replicated. It has also been reported that, compared to normal-weight controls, individuals with higher BMI had higher sensitivity for food odours (herbs) when satiated than when in a hunger state (higher detection threshold, Stafford and Welbeck 2011). These results emphasize the role of hunger and satiety in the perception of food odours, which remain unclear in the literature (Aschenbrenner et al. 2008; Albrecht et al. 2009; Ramaekers et al. 2016).

In contrast, other studies failed to find olfactory capabilities differences linked to BMI or between weight status groups as categories. Those studies indicated that odour identification and detection capabilities (measured by detection threshold tasks) do not seem to differ between individuals with obesity and normal weight (Trellakis et al. 2011), nor between individuals with overweight and normal weight (Skrandies and Zschieschang 2015). A recent study showed that BMI was not related to the olfactory detection threshold or odour identification (Besser et al. 2020).

In terms of odour detection, the use of threshold, as well as suprathreshold assessments, has been reported in the literature when trying to measure olfactory capabilities in relation to obesity.

Absolute threshold detection tasks establish the lowest concentration of an odorant that can be perceived, while suprathreshold tasks allow measuring whether an odorant is detected or not at a given concentration and is often used to assess perceived intensity (Doty 2018). Suprathreshold tasks can also be used in detection evaluations, to check for hyposmia, specific anosmia, or global anosmia. Due to the complexity to evaluate absolute olfactory detection thresholds for several odorants in within-subject designs, we chose to use a measure of suprathreshold olfactory sensitivity through the European Test of Olfactory Capabilities (ETOC). This test was developed by combining a suprathreshold detection task and an identification task (Thomas-Danguin et al. 2003), with the aim to obtain a broader evaluation of olfactory capabilities. While the absolute detection or recognition threshold tests are time-consuming and do not allow to test a large set of odorants, the European Test of Olfactory Capabilities is fast and allows categorizing quickly a high number of participants into smellers and non-smellers for a variety of odorants. This test was therefore chosen to screen a large set of food and non-food odours.

The use of various methodologies (identification tasks, threshold and suprathreshold detection tasks) involving food as well as non-food odorants might have enhanced the discrepancies of results reported in the literature.

To the best of our knowledge, previous studies conducted with large samples of participants on these topics included exclusively or mostly women. Moreover, there are only a few data available on overweight individuals, and no study has compared the olfactory capacities of men and women of various weight statuses towards food vs. non-food odours. Consequently, our objective was to evaluate the olfactory capacities of men and women with normal weight, overweight, and obesity. Based on the literature, our first hypothesis was that individuals of higher weight statuses would have poorer overall olfactory capacities (suprathreshold detection and identification). Secondly, we hypothesized that individuals with overweight and obesity would be more efficient than normal-weight individuals in the suprathreshold detection and identification of food-related odours specifically. To address this aim, we submitted a sample of men and women of various weight statuses to the European Test for Olfactory Capabilities (ETOC) (Thomas-Danguin et al. 2003), a validated test that mixes food and non-food odours.

Material and methods

Participants

One hundred twenty-four participants took part in our experiment. Our sample comprised 41 individuals with normal-weight (BMI $\geqslant 18.5$ and < 25 kg/m^2), 45 individuals with overweight (BMI $\geqslant 25$ and < 30 kg/m^2), and 38 individuals with obesity (BMI $\geqslant 30$ kg/m^2), according to the current norms of weight status categories based on BMI (Nuttall 2015; Komaroff 2016). Participants were between 18 and 60 years old, with a mean age of 42.62 years (SD: 10.78). Forty-one percent of participants were men. Participants were recruited through PanelSens, a database managed by the Chemosens Platform from our research centre that complies with all applicable national data protection rules and has been vetted by the appropriate French authorities (Commission Nationale Informatique et Libertés – CNIL – 135). Participants were first contacted by e-mail and asked whether they would agree to participate in a study in our laboratory. They were asked to complete a questionnaire checking for non-inclusion criteria: chronic disease (such as diabetes, hypertension, or any type of cardiovascular disease), medical treatment that may affect mental awareness, pregnancy, anosmia, chronic sinusitis, and history of bariatric surgery. Those criteria were chosen to avoid olfactory decrease due to medical conditions or medical treatment that could alter olfactory capacities. Once they were recruited, we asked participants to postpone their appointment at the laboratory if they were feeling sick, in order to avoid decreased olfactory capacities due to flu symptoms or cold. The study was conducted in accordance with the Declaration of Helsinki and was approved by an ethics committee (Comité d'Evaluation de l'Ethique de l'Inserm – CEEI, File number IRB 0,000,388,817–417–Project number X 467). This research study adhered to all applicable institutional and governmental regulations concerning the ethical use of human volunteers.

The European Test for Olfactory Capacities (ETOC)

This study used the European Test for Olfactory Capabilities (Thomas-Danguin et al. 2003), which has been validated for the evaluation of olfactory suprathreshold detection and identification capabilities in European adults. The ETOC consists of 16 blocks (identified by numbers) of 4 vials (identified by letters) with only one being odorized while others contain solvent only (cf. Thomas-Danguin et al. 2003 for more details). The test is based on a four alternative-forced choice procedure, so participants have to smell the vials block per block. Within each block, participants had to detect which vial, out of four, contained an odour (*detection task*), and then, to identify the odour in the selected vial by selecting one of the 4 odour names proposed for a given block (*identification task*). Answers were collected on a dedicated answer sheet. The test is based on 16 odours (vanilla, cloves, apple, eucalyptus, cinnamon, fuel–oil, pine, garlic, cut grass, anise, orange, fish, rose, thyme, lemon, and mint). For the purpose of the study, and based on a consensus between the co-authors and the use of such categorization in previous unpublished work, we chose to divide these odours into two categories: 10 are labelled as food-related odours (vanilla, apple, cinnamon, garlic, anise, orange, fish, thyme, lemon, and mint), and 6 can be considered non-food-related odours (cloves, eucalyptus, fuel–oil, pine, cut-grass, rose). Although part of these odorants may be issued from food or used in cooking, they are not common in French culinary tradition. Furthermore, these odorants were used at a concentration sufficiently high to be associated to non-food odours.

The test gives two distinct scores: a *detection score* (out of 16) and an *identification score* (out of 16). The identification can be correct only if the detection is also correct. In order to test our second hypothesis and to capture detection and identification capabilities for these two categories of odours, we separated scores for food-related odours (vanilla, apple, cinnamon, garlic, anise, orange, fish, thyme, lemon, and mint), and scores for non-food odours (cloves, eucalyptus, fuel oil, pine, cut grass, rose).

Session

Participants were asked to come to the laboratory for a session, which was scheduled at 12 p.m. and lasted about 20 min, to perform ETOC measurements. Participants were asked to refrain from eating, drinking anything except water, and smoking for 3 h before the session. This procedure was requested in order to maintain participants in the most odour-neutral conditions and to control their hunger level. Moreover, participants were asked to avoid wearing scented cosmetics like perfume or deodorant, in order to avoid parasite smells during the test. Each session comprised 2 to 6 participants at a time. They were seated in individual testing boxes, with a minimum distance of 1.50 m between participants. The hunger level was assessed for each participant on a 10-point Visual Analog Scale (VAS) before the ETOC. Experimenters gave oral instructions to each participant before they began the test, as well as a written instruction sheet and a response sheet. Experimenters ensured that the instructions were clear for each participant and encouraged them to ask questions by raising their hand if they had any questions about the procedure at any time during the session. When participants indicated that they had finished the test, they were asked to go to another room where an experimenter measured and weighed them individually (in light clothing) to calculate their BMI in kg/m^2.

Data Preparation

To analyse data from the ETOC, we separated the scores for food-related odours (vanilla, apple, cinnamon, garlic, anise, orange, fish, thyme, lemon, and mint), and scores for non-food odours (cloves, eucalyptus, fuel oil, pine, cut grass, rose). To complete our examination, post hoc analyses were performed to measure olfactory capacities towards a subgroup of food odours that are often encountered in sweet desserts and which might cue for energy-dense foods, namely vanilla and cinnamon odours. We examined whether individuals with higher weight status were better at detecting and identifying those odours by creating binary variables for the detection and identification of each of these four odorants.

Statistical Analysis

To assess differences between the three experimental groups (normal-weight, overweight, and obesity), ANOVA was performed for continuous variables (age, BMI, hunger level), and chi^2 tests were used for categorical variables (sex, smoker status). Statistical analysis was performed with R.3.4.3 software (R Development Core Team 2008). The significance threshold was set at 0.05. To measure differences between food and non-food odours, we considered four scores (detection of food odours, detection of non-food odours, identification of food odours, identification of non-food odours), in addition to the overall suprathreshold detection and overall identification scores derived from the ETOC (/16). We separated the scores for the suprathreshold detection and identification of food (/10) and non-food odours (/6).

Linear models were used to evaluate the effects of age, sex, weight status, and hunger levels on detection and identification scores for all the odours, but also for food odours on the one hand and non-food odours on the other hand. The initial model for each score of detection and identification involved four terms: age, sex, weight status, and hunger level, and the two-way interactions between age*weight status and sex*weight status. In the final model, the non-significant terms were removed.

In order to assess the detection and identification capacities for specific energy-dense cues (vanilla and cinnamon separately), exploratory analyses were conducted. Generalized linear models were estimated by considering the binomial variables "detection" and "identification" for each odour as a dependent variable and age, sex, weight status, and hunger level as covariates.

Results

No differences were found between the normal weight, overweight, and obesity groups in terms of age, sex, hunger level, and smoker status. Participants' characteristics are detailed in Table 1.

Suprathreshold Detection Scores

For all models concerning suprathreshold detection scores (overall, food odours, and non-food odours), only the effect of age was significant. For overall suprathreshold detection scores, the detection score decreased by 0.25% per additional year of age ($F_{(1, 122)} = 6.90$, $p = 0.02$). Concerning food odours, the detection score decreased by 0.2% per additional year of age ($F_{(1, 122)} = 8.69$, $p = 0.004$). Finally, for non-food odours, the detection score decreased by 0.03%

Table.1 Participants' characteristics. Means (SD) are represented for continuous variables. *$p < 0.05$

	Normal weight ($n = 41$)	Overweight ($n = 45$)	Obesity ($n = 38$)	p-value
Age	43.66 (11.06)	43.31 (9.11)	40.71 (12.26)	0.42
BMI	22.00 (1.76)	27.33 (1.42)	36.03 (5.16)	< 0.001*
Sex (F/M)	26/25	22/23	24/14	0.29
Hunger level	6.47 (2.75)	6.10 (2.81)	5.72 (2.75)	0.49
Smoker status				0.09
Current smoker	1	4	7	
Former smoker	11	17	9	
Never smoked	29	24	22	

per additional year of age ($F_{(1,122)} = 4.60$, $p = 0.03$). Contrary to our hypotheses, no significant effect was found for weight status on detection scores, whatever the odour category [*food odours*: $F_{(2,118)} = 0.41$, $p = 0.66$; *non-food odours*: $F_{(2,118)} = 0.16$, $p = 0.85$; *overall*: $F_{(2, 118)} = 0.34$, $p = 0.71$].

Identification Scores

The effect of age and the effect of sex were significant on all identification measurements. For overall identification ($F_{(1, 121)} = 14.61$, $p < 0.001$), the score decreased by 0.07 per additional year of age. Women had, on average, higher scores than men ($F_{(1,121)} = 8.05$, $p = 0.005$; women vs. men = + 1.31, SD = 0.46). Concerning the effect of age on the identification of food odours, the score decreased by 0.05 per additional year of age ($F_{(1, 121)} = 12.94$, $p < 0.001$). Women had higher scores than men ($F_{(1,121)} = 4.11$, $p = 0.04$; women vs. men = + 0.59, SD = 0.29).

After non-significant terms were removed from a model with principal effects of the variables age, sex, weight status, and hunger level, only age ($F_{(1,119)} = 5.76$, $p = 0.02$) and sex ($F_{(1,119)} = 13.75$, $p < 0.001$) remained significant. The identification score for non-food odours decreased by 0.02 per year of age and was higher in women (women vs. men = 0.78, SD = 0.21). Interestingly, the effect of weight status on non-food odour identification was marginally significant ($F_{(2, 119)} = 2.99$, $p = 0.05$). Participants with overweight (mean: + 0.69, SD = 0.25, $p = 0.005$) and obesity (+ 0.45, SD 0.26, $p = 0.07$) tended to have higher identification scores for non-food odours than the normal-weight group. This result is not in line with our hypothesis since we expected that participants with overweight and participants with obesity would have higher olfactory capabilities for food odours, but not for non-food ones. All data are reported in Table 2.

Table.2 Effects of age and sex on ETOC suprathreshold detection and identification scores, for overall score, food score and non-food score. $^*p < 0.05$

	Variable	Estimate	SD	*p*-value
ETOC detection scores				
Overall	Age	− 0.04	0.015	0.01*
Food	Age	− 0.02	0.008	0.004*
Non-food	Age	− 0.02	0.008	0.03*
ETOC identification scores				
Overall	Age	− 0.07	0.02	< 0.001*
	sex (M vs. F)	− 1.31	0.46	0.005*
Food	Age	− 0.045	0.01	0.001*
	sex (M vs. F)	− 0.59	0.29	0.045*
Non-food	Age	− 0.018	0.01	0.06
	sex (M vs. F)	− 0.77	0.21	< 0.001*

Results for Specific Energy-Dense Cues

For the exploratory analysis of specific food-related odours that might cue for high-energy dense foods (vanilla and cinnamon), we aimed at assessing whether individuals were more prone to detect and identify each odour according to weight status. No statistical differences were observed, meaning that individuals with normal weight, overweight, and obesity did not have different olfactory capabilities for sweet energy-dense food cues, contrary to our hypotheses. However, a marginally significant contrast is to be noted: participants with overweight were more likely to correctly identify vanilla than participants with normal weight ($p = 0.05$). The results are shown in Table 3.

Discussion

Our objective was to evaluate olfactory capacities (detection and identification) of men and women with normal-weight, overweight, and obesity by comparing their olfactory capacities for food vs. non-food odours. Our results show that there are no weight-status-related differences in olfactory capacity relative to the suprathreshold detection and identification of food odours, nor in overall odour suprathreshold detection and identification capabilities.

Sex Differences

Our results show that the identification capacities of men and women are different. Women had higher scores, reflecting that they were better able to identify food and non-food

Table.3 Percentage of incorrect suprathreshold detections and identifications of energy-dense food cues as a function of weight status group. The significance threshold was set at $p = 0.05$

Odour	Task	Normal-weight ($n = 41$)	Overweight ($n = 45$)	Obesity ($n = 38$)	*p*-value (weight status)
Vanilla	Detection	0	2.2	2.6	0.47
	Identification	34.1	17.8	23.6	0.14
Cinnamon	Detection	0	2.2	0	0.33
	Identification	14.6	11.1	7.9	0.72

odours. This result was previously observed in several other studies (for a review, see Sorokowski et al. 2019). Women may have higher identification capacities because identification capacities rely on cognitive aspects such as verbal memory, verbal fluency, and semantic knowledge and women perform better in these areas (Larsson et al. 2004; Sorokowski et al. 2019). These results have also been observed in children (Monnery-Patris et al. 2009), but vanished when the effect of sex was corrected for verbal performance, suggesting that the better identification of odours in girls might only be due to superior verbal performance (Monnery-Patris et al. 2009).

Influence of Age

We found that suprathreshold detection and identification of odours were influenced by age. This result is congruent with the literature, considering that aging has been linked with olfactory performance decline (Thomas-Danguin et al. 2003; Arikawa et al. 2020). The effects of aging are different from one individual to another, and factors such as poor health status and medication use appear to modulate olfactory performance in older adults (Sulmont-Rossé et al. 2015; Kondo et al. 2020). Several studies showed that olfactory decline involved in the poor perception of food flavour can lead to changes in eating behaviour in elderly people (Duffy et al. 1995; Schiffman 2000). However, in 2006, Simchen et al. showed that higher BMI had a protective effect on olfactory capacities in 65 years and older adults (Simchen et al. 2006). In their study, individuals younger than 65 years old with lower BMI (< 28 kg/m^2) had better olfactory capacities (detection and identification) than individuals with overweight or obesity (BMI > 28 kg/m^2) in the same age group. This relationship was reversed after the age of 65, and individuals with overweight or obesity (BMI > 28 kg/m^2) had better olfactory performances. In the present study, no interaction between age and weight status was observed in terms of olfactory capabilities, which may be explained by the fact that participants were younger than 60 years old in our studied set.

Weight Status

Contrary to our hypotheses, no difference in olfactory capabilities towards food odours related to weight status was found. Consequently, such a result adds to the literature indicating that when health parameters are controlled, weight status does not seem to influence olfactory performance in healthy individuals with obesity. An explanation of such findings might be that individuals with a metabolically healthy phenotype of obesity (MHO) might be protected from the impact of obesity on olfactory functions. Some recent findings indeed show that inflammatory processes in individuals with metabolic obesity could reduce the size of the olfactory bulb, which is negatively correlated to performance in the identification and detection of odours (Poessel et al. 2020). Rather than weight status, a relationship with the diet should also be investigated. Indeed, having a western diet (high in fat, sugar, salt and low in fibres) might lead to overweight and obesity, but also modulate olfactory perception. The usual consumption of few foods with volatile contents (such as fruits and vegetables) and a high proportion of fat in the diet has been linked to a weaker perception of oral olfactory cues. This can lead to different experiences with food in general and induce different olfactory abilities towards foods (Stevenson et al. 2016). Individuals with overweight/obesity might have different dietary patterns that cannot be summarized by taking only weight status into account. This hypothesis could explain the absence of significant results in our study, and constitute an interesting path for future research looking to disentangle the relationship between olfaction, food consumption, and weight status.

In post hoc exploratory analyses, no differences were observed for the specific detection or identification of high energy-dense food cues, except for a tendency of better identification of vanilla in individuals with overweight (but not with obesity) that needs to be confirmed on a larger sample. In 2015, Stafford et al. measured preference and sensitivity to a chocolate odour in participants with obesity by using threshold measurements and showed that individuals with obesity had higher preferences for chocolate as well as increased sensitivity (lower detection threshold) to this odour (Stafford and Whittle 2015). There are two major differences between this experiment and our study. First, the absence of significant results in our study might result from the supraliminal concentrations of odorants in the ETOC: the ETOC consists in a suprathreshold detection task, while Stafford et al. used absolute detection threshold measurements, which are two different tasks. Secondly, the ETOC used pleasant and unpleasant odours while Stafford et al. only used one pleasant odour. Chocolate is a highly palatable food that is often linked to pleasure, both as an ingredient (in cakes, pastries, and sweets), and as a food (snack, dessert). The palatability and the pleasantness of the chocolate odour used in Stafford et al.'s work might activate hippocampal mechanisms related to memory and consumption context. Indeed, in 2010, Bragulat et al. (2010) used functional imagery to assess brain activity in individuals with obesity and normal weight exposed to preferred food odours (fat or sweet food odours) vs. nonappetitive odours. They observed that brain activity in an odour perception task was different between individuals with obesity and with normal weight: for individuals with obesity, activity in the hippocampal/parahippocampal gyrus was higher for preferred food odours vs. non-food odours, compared to normal-weight individuals (Bragulat et al. 2010). Sensitivity to food odours could be then related to the pleasantness of the odour that is due to previous hedonic experiences with it rather than the general properties of the actual food (low vs. high energy density). Our results encourage us to further investigate olfactory capabilities for food odours in individuals with various weight statuses. Indeed, vanilla odour (vanillin) might be a good candidate as it is a pleasant sweet-congruent food odour (Koubaa and Eleuch 2020), and its inhalation has been shown to increase food intake in mice, suggesting that vanilla might activate some mechanisms tied to appetite regulation (Ogawa et al. 2018).

For the identification of non-food odours, a marginally significant effect was found for weight status, indicating that individuals with higher weight statuses might have a higher identification capacity for non-food odours. Even if not statistically significant, this result can be surprising. Indeed, the few studies on olfactory capacities for food odours and weight status reported that individuals with obesity had better detection abilities (in terms of odour detection threshold) for food odours (Stafford and Welbeck 2011; Stafford and Whittle 2015). Such a relationship between odour detection performance and weight status was not replicated in our study with the major difference that our detection task was based on supraliminar detection and not on detection threshold. One recent study (Nettore et al., 2020) showed that individuals with obesity had higher identification abilities for orally delivered food odours rather than olfactory orthonasal perception as in our study. In contrast, we did not observe better identification scores for food odours in participants with obesity throughout the study, which suggests a different impact of retronasal and orthonasal perception of food odours on identification capabilities and in turn differences concerning distal and proximal reactions to food odour according to weight status. To our knowledge, the present study is the first to document the identification of food odours in individuals with various weight statuses by also assessing the identification of non-food odours in the same experimental design.

Hunger Level

Finally, the hunger level of our participants did not influence their olfactory performance. Moreover, the studies looking at the relationship between hunger, satiety, and olfactory sensitivity have failed to find a clear explanation (Albrecht et al. 2009; Stafford and Welbeck 2011; Ramaekers et al. 2016). Some hormonal changes linked to specific conditions of obesity and related to food intake might be worth taking into account. Indeed, Fernandez-Aranda et al. (2016) observed that circulating levels of ghrelin (the hormone increasing food intake) were negatively correlated with olfactory capacities and with BMI. Also, Fernandez-Garcia (2017) found that identification, detection, and olfactory thresholds were correlated with the percentage of visceral fat mass. Individuals with various BMIs may have different proportions of visceral fat, and hormonal effects linked to the percentage of visceral fat mass might better explain the decreased olfactory performance in individuals with higher weight statuses than weight status alone. It would be interesting to replicate our study with the addition of hunger/satiety conditions within weight status groups, and the measurement of visceral fat mass.

Strengths and Limitations

One of the strengths of our study is that data were collected on women and men participants of various weight statuses, which is quite rare in the domain of olfactory capabilities research. Contrary to several previous studies, hunger level was measured before testing, and we avoided the inclusion of participants with medical diseases or taking medications that could have modified their olfactory capacities. Smoking status was controlled: participants were mostly non-smokers at the time of the experiment and smoking status was not statistically differently distributed between our three experimental groups. A recent meta-analysis showed that former smokers do not have a higher risk for olfactory dysfunction (Ajmani et al. 2017). Concerning actual smokers, they were mostly mild smokers (less than 9 cigarettes a day, indicating a moderate impact of smoking on smell (Vennemann et al. 2008), data not shown) and we requested them to avoid smoking at least three hours before the session.

Our study presents some limits. First, the categorization of the food vs. non-food odours was based on a consensus between the six co-authors, and has not been tested in a categorization test with participants prior to the study. For instance, we did not include eucalyptus and rose as food odours as they are not culturally considered typical food items in French culture. We also considered cloves as a non-food odour; non-users of clove as a spice are less likely to correctly identify it in a food context (Knaapila et al. 2017). Also, the clove odour can be associated with medical care as eugenol (or "clove oil") is often used as a local anaesthetics by dentists (Milind and Deepa 2011). Hence, we encourage further research to study whether the odorants used in the ETOC lead to food or non-food odour categorization in participants, as it could be really useful for the field. Moreover, the study of detection and identification of specific sweet-congruent food odorants (i.e. vanilla and cinnamon) was exploratory, but might be interesting for future studies about the relationship between obesity and high-energy dense cues. Finally, our results for olfactory detection have been shown on a suprathreshold detection task (Thomas-Danguin et al. 2003). Even if the detection scores might reflect some degree of sensitivity, it is not a measure of absolute sensitivity as are detection threshold measurements. Olfactory threshold measurements (for example, with an olfactometer) would have been a more precise way to capture variability in absolute sensitivity in relation to weight status. Indeed, studies using threshold measurements have often revealed differences between individuals of various weight statuses (Skrandies and Zschieschang 2015; Fernandez-Garcia et al. 2017). However, such studies have been conducted on samples comprising mostly women, with a lack of control of the course of their menstrual cycle. This variable has been widely proven to be a strong modulator of olfactory thresholds. Several studies have indeed shown that the olfactory threshold is significantly different between the fertile and non-fertile phases of the menstrual cycle, and especially concerning food odours detection (for a review, see Nováková et al. 2014a). These results, combined with those found by Fernandez-Garcia and Fenrandez-Aranda suggest that hormonal status has an important role in olfaction (Fernández-Aranda et al. 2016; Fernandez-Garcia et al. 2017). It would be of great interest to conduct further research to evaluate olfactory capacities in a sample comprising an equal proportion of men and women (controlling for the course of the menstrual cycle), of various weight statuses (normal-weight, overweight, and obesity, as well as massive obesity — BMI $\geqslant 40$ kg/m^2).

Conclusion and Perspectives

Our study did not find evidence for a relationship between olfactory capacity and weight status. We do not exclude the hypothesis that a decrease in olfactory capacities may be linked to some form of obesity, but it seems likely that olfactory dysfunction in obesity is rather related to higher absolute sensitivity than to suprathreshold detection or identification capacities. Indeed, results from the most controlled studies (sex ratio, sample size, comorbidities, etc.) of the literature suggesting that individuals with obesity have a poorer sense of smell were based on odour detection threshold measurements. Concerning food odours, our results show that individuals with normal weight, overweight, and obesity tend to have similar olfactory capacities towards food and non-food odours, regardless of their hunger state. We propose that previously observed heightened sensitivity in individuals with higher weight statuses might be linked to cognitive processing of the odours (pleasantness, previous experiences) rather than to the "food" aspect. Also, hormonal changes and metabolic status seem to play a role in the olfactory capacities of individuals with obesity. It would be interesting to conduct additional studies regarding the olfactory capacities of individuals with obesity, especially taking into account individual characteristics that can affect olfactory capacities, such as the percentage of visceral fat and the hormonal status of ghrelin and leptin, as well as the course of the menstrual cycle. Because olfactory capacities seem to rely on memory and context for individuals, an investigation of cognitive factors (familiarity, pleasantness) underlying this effect for food odours should be pursued concerning weight status. Our study also hinted at differences in the identification of non-food odours, so we think that there is a need for further research on differentiation of food and non-food odours in the study of olfactory capacities.

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Declarations

Conflict of Interest The authors declare no competing interests.

References

Ajmani GS et al (2017) Smoking and olfactory dysfunction: a systematic literature review and meta-analysis. Laryngoscope 127(8):1753–1761. https://doi.org/10.1002/lary.26558

Albrecht J et al (2009) Olfactory detection thresholds and pleasantness of a food-related and a non-food odour in hunger and satiety. Rhinology 47(2):160–165

Appelhans BM (2009) Neurobehavioral inhibition of reward-driven feeding: implications for dieting and obesity. Obesity 17(4):640–647. https://doi.org/10.1038/oby.2008.638

Arikawa E et al (2020) Influence of olfactory function on appetite and nutritional status in the elderly requiring nursing care. J Nutr Health Aging 24(4):398–403. https://doi.org/10.1007/s12603-020-1334-3

Aschenbrenner K et al (2008) The influence of olfactory loss on dietary behaviors. Laryngoscope 118(1):135–144. https://doi.org/10.1097/MLG.0b013e318155a4b9

Berridge KC (2009) "Liking" and "wanting" food rewards: brain substrates and roles in eating disorders. Physiol Behav 97(5):537–550. https://doi.org/10.1016/j.physbeh.2009.02.044

Berridge KC et al (2010) The tempted brain eats: pleasure and desire circuits in obesity and eating disorders. Brain Res 1350:43–64. https://doi.org/10.1016/j.brainres.2010.04.003

Besser G et al (2020) Body-mass-index associated differences in ortho- and retronasal olfactory function and the individual significance of olfaction in health and disease. J Clin Med 9(2):366. https://doi.org/10.3390/jcm9020366

Boesveldt, S. (2017) 'Olfaction and eating behavior', in Buettner, A. (ed.) Springer Handbook of Odor. Springer International Publishing (Springer Handbooks), pp. 109–110. Available at: https://www.springer.com/gp/book/9783319269306 (Accessed: 25 Jul 2020).

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

Bragulat V et al (2010) Food-related odor probes of brain reward circuits during hunger: a pilot fMRI study. Obesity 18(8):1566–1571. https://doi.org/10.1038/oby.2010.57

Djordjevic J, Zatorre RJ, Jones-Gotman M (2004) Odor-induced changes in taste perception. Exp Brain Res 159(3):405–408. https://doi.org/10.1007/s00221-004-2103-y

Doty RL (2018) Measurement of chemosensory function. World J Otorhinolaryngol Head Neck Surg 4(1):11–28. https://doi.org/10.1016/j.wjorl.2018.03.001

Doty RL, Laing DG (2015) Psychophysical measurement of human olfactory function, in Handbook of Olfaction and Gustation. John Wiley & Sons, Ltd, pp. 225–260. https://doi.org/10.1002/9781118971758.ch11

Duffy VB, Backstrand JR, Ferris AM (1995) Olfactory dysfunction and related nutritional risk in free-living, elderly women. J Am Diet Assoc 95(8):879–884. https://doi.org/10.1016/S0002-8223(95)00244-8

Fernández-Aranda F et al (2016) Smell–taste dysfunctions in extreme weight/eating conditions: analysis of hormonal and psychological interactions. Endocrine 51(2):256–267. https://doi.org/10.1007/s12020-015-0684-9

Fernandez-Garcia JC et al (2017) An increase in visceral fat is associated with a decrease in the taste and olfactory capacity. PLoS ONE 12(2):e0171204. https://doi.org/10.1371/journal.pone.0171204

Joyner MA, Kim S, Gearhardt AN (2017) Investigating an incentive-sensitization model of eating behavior: impact of a simulated fast-food laboratory. Clinical Psychological Science 5(6):1014–1026. https://doi.org/10.1177/2167702617718828

Knaapila A et al (2017) Pleasantness, familiarity, and identification of spice odors are interrelated and enhanced by consumption of herbs and food neophilia. Appetite 109:190–200. https://doi.org/10.1016/j.appet.2016.11.025

Komaroff M (2016) For researchers on obesity: historical review of extra body weight definitions. J Obes. https://doi.org/10.1155/2016/2460285

Kondo K et al (2020) Age-related olfactory dysfunction: epidemiology, pathophysiology, and clinical management, Front Aging Neurosci, 12. https://doi.org/10.3389/fnagi.2020.00208

Koubaa Y, Eleuch A (2020) Gender effects on odor-induced taste enhancement and subsequent food consumption. J Consum Mark. https://doi.org/10.1108/JCM-02-2019-3091

Larsson M et al (2004) Demographic and cognitive predictors of cued odor identification: evidence from a population-based study. Chem Senses 29(6):547–554. https://doi.org/10.1093/chemse/bjh059

Mas M et al (2019) Weight status and attentional biases toward foods: impact of implicit olfactory priming. Front Psychol. 10. https://doi.org/10.3389/fpsyg.2019.01789

Mas M et al (2020) Implicit food odour priming effects on reactivity and inhibitory control towards foods. PLoS ONE 15(6):e0228830. https://doi.org/10.1371/journal.pone.0228830

Milind P, Deepa K (2011) Clove: a champion spice. Int J Res Ayurveda Pharm (IJRAP) 2(1):47–54

Monnery-Patris S et al (2009) Development of olfactory ability in children: sensitivity and identification. Dev Psychobiol 51(3):268–276. https://doi.org/10.1002/dev.20363

Nettore IC et al (2020) Flavor identification inversely correlates with body mass index (BMI). Nutr Metab Cardiovasc Dis 30(8):1299–1305. https://doi.org/10.1016/j.numecd.2020.04.005

Nováková LM, Havlíček J, Roberts SC (2014a) Olfactory processing and odor specificity: a meta-analysis of menstrual cycle variation in olfactory sensitivity. Anthropol Rev 77(3):331–345. https://doi.org/10.2478/anre-2014-0024

Nováková L, Varella Valentova J, Havlíček J (2014b) Engagement in olfaction-related activities is associated with the ability of odor identification and odor awareness. Chemosens Percept 7(2):56–67. https://doi.org/10.1007/s12078-014-9167-2

Nuttall FQ (2015) Body mass index. Nutr Today 50(3):117–128. https://doi.org/10.1097/NT.0000000000000092

Ogawa K et al (2018) Appetite-enhancing effects of vanilla flavours such as vanillin. J Nat Med 72(3):798–802. https://doi.org/10.1007/s11418-018-1206-x

Peng M et al (2019) Systematic review of olfactory shifts related to obesity. Obes Rev 20(2):325–338. https://doi.org/10.1111/obr.12800

Poessel M et al (2020) Reduced olfactory bulb volume in obesity and its relation to metabolic health status. Front Human Neurosci. 14. https://doi.org/10.3389/fnhum.2020.586998

R Development Core Team (2008) R: a language and environment for statistical computing. Vienna, Austria: R Foundation for Statistical Computing. Available at: https://www.r-project.org. Accesed 14 October 2018

Ramaekers MG et al (2014) Odors: appetizing or satiating? Development of appetite during odor exposure over time. Int J Obes 38(5):650–656. https://doi.org/10.1038/ijo.2013.143

Ramaekers MG et al (2016) Metabolic and sensory influences on odor sensitivity in humans. Chem Senses 41(2):163–168. https://doi.org/10.1093/chemse/bjv068

Richardson BE et al (2004) Altered olfactory acuity in the morbidly obese. Obes Surg 14(7):967–969. https://doi.org/10.1381/0960892041719617

Robinson TE, Berridge KC (1993) The neural basis of drug craving: an incentive-sensitization theory of addiction. Brain Res Brain Res Rev 18(3):247–291

Schiffman SS (2000) Intensification of sensory properties of foods for the elderly. J Nutr 130(4):927S-930S. https://doi.org/10.1093/jn/130.4.927S

Simchen U et al (2006) Odour and taste sensitivity is associated with body weight and extent of misreporting of body weight. Eur J Clin Nutr 60(6):698–705. https://doi.org/10.1038/sj.ejcn.1602371

Skrandies W, Zschieschang R (2015) Olfactory and gustatory functions and its relation to body weight. Physiol Behav 142:1–4. https://doi.org/10.1016/j.physbeh.2015.01.024

Sorokowski P et al (2019) Sex differences in human olfaction: a meta-analysis. Front Psychol. 10. https://doi.org/10.3389/fpsyg.2019.00242

Stafford LD, Welbeck K (2011) High hunger state increases olfactory sensitivity to neutral but not food odors. Chem Senses 36(2):189–198. https://doi.org/10.1093/chemse/bjq114

Stafford LD, Whittle A (2015) Obese individuals have higher preference and sensitivity to odor of chocolate. Chem Senses 40(4):279–284. https://doi.org/10.1093/chemse/bjv007

Stevenson RJ (2010) An initial evaluation of the functions of human olfaction. Chem Senses 35(1):3–20. https://doi.org/10.1093/chemse/bjp083

Stevenson RJ et al (2016) Chemosensory abilities in consumers of a Western-style diet. Chem Senses 41(6):505–513. https://doi.org/10.1093/chemse/bjw053

Sulmont-Rossé C et al (2015) Evidence for different patterns of chemosensory alterations in the elderly population: impact of age versus dependency. Chem Senses 40(3):153–164. https://doi.org/10.1093/chemse/bju112

Thiebaud N et al (2014) Hyperlipidemic diet causes loss of olfactory sensory neurons, reduces olfactory discrimination, and disrupts odor-reversal learning. J Neurosci 34(20):6970–6984. https://doi.org/10.1523/JNEUROSCI.3366-13.2014

Thomas-Danguin T et al (2003) Development of the ETOC: a European test of olfactory capabilities. Rhinology 41(3):142–151

Thomas-Danguin TT et al (2016) 'Multimodal interactions', in Etievant, P. et al. (eds) Flavor. From food to behaviors, wellbeing and health. Elsevier Ltd (Woodhead Publishing Series in Food Science, Technology and Nutrition, 299), pp. 121–141. https://doi.org/10.1016/B978-0-08-100295-7.00006-2.

Trellakis S et al (2011) Ghrelin, leptin and adiponectin as possible predictors of the hedonic value of odors. Regul Pept 167(1):112–117. https://doi.org/10.1016/j.regpep.2010.12.005

Vennemann MM, Hummel T, Berger K (2008) The association between smoking and smell and taste impairment in the general population. J Neurol 255(8):1121–1126. https://doi.org/10.1007/s00415-008-0807-9

Zoon HFA, De Graaf C, Boesveldt S (2016) Food odours direct specific appetite. Foods 5(1):12. https://doi.org/10.3390/foods5010012