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Appetite

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Abstract

Alliesthesia is the modulation of the rewarding value of a stimulus according to the internal state (hungry or satiated). This study aimed to evaluate this phenomenon as a function of the nature of the stimulus (odors evoking edible and non-edible items, and the food odors evoking fatty and non-fat foods) and to compare the effectiveness of two reward evaluations (measures of pleasantness and appetence) to reveal alliesthesia. The results showed that both fatty and non-fat food odors were judged as less pleasant and less appetent when the subjects were satiated than when they were hungry, whereas no such difference was observed for non-food odors. There was a greater decrease in appetence than there was in pleasantness. Moreover, the decrease in appetence was greater for fatty than for non-fat food odors, whereas the decrease in pleasantness was similar for both fatty and non-fat food odors. Our study allows for the definition of a more comprehensive pattern of alliesthesia based on odor category. It demonstrates that alliesthesia is specific to food odors and that it is more pronounced when odors are associated with fatty rather than non-fat foods. It also reveals that an appetence measure is more sensitive than a pleasantness measure for describing an acute reward modulation process.

Keywords: Alliesthesia, Fat, Pleasantness, Appetence, Odor, Internal state

1. Introduction

An internal state of hunger or satiety is well-known to influence food perception. Cabanac (1971) suggested the term *alliesthesia* to describe the fact that a sensory stimulus can generate pleasant or unpleasant feelings depending on the internal state of the consumer. In fact, studies presenting food-related stimuli to participants have shown that the same stimulus can be perceived as either pleasant during a state of hunger (positive alliesthesia) or unpleasant during a state of satiety (negative alliesthesia) (Cabanac & Fantino, 1977; Cabanac et al., 1968; Laeng et al., 1993; Scherr & King, 1982).

Alliesthesia was first studied using paradigms in which pleasantness of one or two foods was evaluated both before and after ingestion of a glucose load (Cabanac, 1971; Cabanac & Fantino, 1977) or a snack (Scherr & King, 1982). This approach presents the benefit of simulating everyday life processes concerning food pleasantness in the context of meal consumption. However, these studies evaluated a low number of foods and, because alliesthesia could be item-specific, results may be biased. One method employed to address this limitation is the use of visual items. In comparison to gustatory stimuli, visual stimuli are easier to create and manipulate and numerous pictures can be presented in the same experiment. Therefore, alliesthesia has often been explored using large sets of visual items depicting foods that were evaluated before and/or after an *ad libitum* lunch (Finlayson et al., 2007; Lozano et al., 1999; Stoeckel et al., 2007). However, the best compromise between plausibility and convenience is probably reached with the use of odorous stimuli. Odors are naturally part of the signal perceived during food ingestion (Yeomans, 2006) and are thus appropriate for studying alliesthesia for food items; moreover, they are easier to use than real food. In addition, memories based on odors are more emotional than memories associated with visual, tactile, auditory or verbal items (Goddard et al., 2005; Herz, 1998; Willander & Larsson, 2007). Odors are therefore relevant cues for studying food pleasantness and have been used in a limited number of studies about alliesthesia (Albrecht et al., 2009; Duclaux et al., 1973; Jiang et al., 2008).

The small number of experiments addressing alliesthesia has given rise to a partial characterization of this phenomenon. It has been clearly demonstrated that negative alliesthesia predominantly concerns food items in comparison to non-food items (Duclaux et al., 1973; Jiang et al., 2008; Stoeckel et al., 2007). The demonstration of alliesthesia-specificity has been refined in a recent study showing that even for fasting-induced positive alliesthesia, its magnitude varies among the food categories studied (desserts, junk foods, entrées, breakfasts, and fruits and vegetables; although only in females in comparison with males), with alliesthesia being lowest for foods with the highest hedonic valence ratings (Stoeckel et al., 2007). It has also been shown that besides the effect of the stimulus' hedonic value, the food category itself could impact the magnitude of alliesthesia (Jiang et al., 2008): odors of energy-rich foods are more affected by the hunger/satiety state than odors of less caloric foods. The authors suggested that the usual order of consumption of the food within a meal might be involved, and that food energy density might also affect alliesthesia amplitude. Collectively, the findings support the idea that alliesthesia could depend on the intrinsic characteristics of foods. Given that humans prefer fatty foods (Drewnowski, 1997; Nysenbaum & Smart, 1982) and the preference enhancement for high-fat food after food deprivation (Lucas & Sclafani, 1996; Sclafani & Ackroff, 1993) in rats, we hypothesized that the lipid composition of food is a crucial factor influencing alliesthesia.

Alliesthesia was first demonstrated through changes in the pleasantness ratings of food-related items (Cabanac, 1971; Cabanac & Fantino, 1977; Duclaux et al., 1973; Laeng et al., 1993; Scherr & King, 1982; Stoeckel et al., 2007). However, Berridge et al. (Berridge, 1996; Berridge & Kringelbach, 2008) stated that affect or pleasure following ingestion of food (*liking*) is only one component of a food's rewarding qualities. Another one is the desire or motivation to consume the food item (*wanting*). Two recent papers have revealed that negative alliesthesia induced by a modification of the internal state influences both liking and wanting of both food odors and pictures (Finlayson et al., 2007; Jiang et al., 2008). However, a comparison between these two evaluation methods has not been performed to test whether one outperforms the other in the detection of the internal state effect on a food-stimulus reward. Given that appetence, but not pleasantness, refers to the desire to consume, we hypothesized that alliesthesia would be better characterized by changes in the appetence rather than the pleasantness of food-related stimuli.

The aim of the current study was to evaluate the influence of the internal state (hunger *vs*. satiety) on the rewarding value of odors as a function of their nature. We distinguished food odors from non-food odors, and we distinguished odors that evoke fatty foods from those that evoke non-fat foods. We evaluated the odors' desirability using both the liking (pleasantness) and wanting (appetence) measures to compare their efficiency at reflecting the phenomenon of alliesthesia. The nature of the odor and its inclusion in a category was assessed in a preliminary experiment.

2. Preliminary experiment

2.1. Objective

The aim of the Preliminary Experiment was to select and place odorants into three categories of interest: non-food (NFood), non-fat food (NFat) and fatty food (Fat) odors. The criterion for odor selection was that the three odor groups had to differ in terms of edibility and fattiness, but not in terms of other dimensions (intensity, familiarity, arousal, sweetness, typicality) to any great extent. Pleasantness and appetence were used to describe the liking and wanting dimensions, respectively.

2.2. Materials and Methods

2.2.1. Participants

Thirty-two naïve volunteers (age range, 18 to 35 years; mean, 28 years; 20 females) took part in the experiment. Participants were recruited by means of posters on the campus or by phone using a volunteers' database approved by the French authority ensuring data privacy (CNIL, authorization N°1148039). The investigations were performed in accordance with the Declaration of Helsinki. Participants received written and oral information about the study and signed a consent form. All subjects reported a normal sense of smell and an absence of food allergy. They were instructed to fast (but they could drink plain water) 2 hours prior to the experiment. They received a 30 euro compensation.

2.2.2. Odorants

Sixty odorants were selected *a priori* based on their distinctiveness, high familiarity and relatively positive valence. They were divided into three categories of

20 odors each: Fat, NFat, and NFood. They consisted of essential oils, food flavors, food and non-food products, and single or a mixture of monomolecular chemicals. The concentrations of the odorants were adjusted by three experimenters (authors of the paper: NL, CSR, JP) during successive trials, in order to equalize the subjective intensity of all olfactory stimuli. The odorants were diluted using mineral oil (Sigma-Aldrich, Saint-Quentin-Fallavier, France) or distilled water depending on their solubility.

The odorants were presented in 60-ml brown glass jars (VWR, Briare-le-Canal, France) in which 10 ml of the odorant was placed onto an absorbent (Codima Rhone Protec, Décines, France) in order to maximize the exchange area between the odorant solution and the air in the jar. The solutions were prepared three days prior to the experiment and stored at 4 °C. They were placed at ambient temperature the day before the experiment. A random three-digit code was assigned to each jar sample.

2.2.3. Experimental paradigm

Odorant evaluation took place in a sensory room equipped according to the AFNOR standard (Association Française de NORmalisation, 1987) at a temperature of 20 ± 0.5 °C. In order to limit the duration of the sessions and thereby reduce the adaptation effect, the experiment was conducted in three 60-min sessions taking place on consecutive days. The presentation order of the 60 odorants was pseudo-randomized in such a way that during each session, subjects were presented 20 odorants, including 6 to 7 odors from each category. Within a session, the subjects did not receive more than three consecutive odorants from the same category (the order was varied among participants both within and between sessions). For each odorant, the subjects were instructed to open the jar and smell the odorant through normal breathing. They were asked to evaluate the odorants using a series of visual analogue scales. They provided ratings for the following attributes. *Intensity*: “Intensity of this odor is” (anchors “extremely weak” and “extremely strong”). *Pleasantness*: “This odor is” (anchors “extremely unpleasant” and “extremely pleasant”). For this attribute, we added a mid-point corresponding to “neutral”. *Arousal*: “While smelling this odor, the intensity of the emotional response you are experiencing is” (anchors “extremely weak” and “extremely strong”). *Edibility*: “Does this odor evoke a food odor?” (anchors “not at all” and “very strongly”). *Appetence*: “Would you like to consume a food with this odor?” (anchors “not at all” and “very strongly”). *Fattiness*: “Is this odor fat?” (anchors “not at all” and “very strongly”). *Sweetness*: “Is this odor sweet?” (anchors “not at all” and “very strongly”). *Familiarity*: “Is this odor known to you?” (anchors “unknown” and “very well-known”). *Typicality*: “Is this odor typical of a *label* smell?” with *label* being a representative label of the odor (anchors “not at all typical” and “very typical”). The order of the rating scales was identical for all odorants and subjects (intensity; pleasantness and arousal; edibility and appetence; fattiness and sweetness; familiarity; typicality). Between odorants, a 30-sec rest time was imposed on the subjects in order to minimize sensory adaptation.

2.2.4. Data analysis

Responses on the 12-cm visual analogue scales were converted into scores varying from 0 to 10. Statistical analyses were conducted using the SAS/STAT® version 9.1 statistical software package (SAS Institute, Cary, NC). All the analyses of variance (ANOVA) were performed with the general linear model procedure of SAS. The normality of samples and the homogeneity of their variance were controlled with the

Kolmogorov-Smirnov test and the Bartlett test, respectively. *Post-hoc* comparisons of means were computed for each significant factor by using the 'least-squares means' option of the general linear model procedure. All results reported here were significant at the 0.05 level unless otherwise noted. Means are given with their standard error (s.e.).

2.3. Results

First, in order to determine the relation between the odor attributes of interest (pleasantness and appetence), we computed Pearson's correlation coefficients between those two attributes, using the mean scores from all subjects for each of the 60 odors. A significant positive relationship between pleasantness (testing the liking dimension) and appetence (testing the wanting dimension) ($r = 0.51$; $p < 0.001$) was found. Then, in order to identify the specificities of each of these attributes, we studied their relationship with intensity, arousal and familiarity (Significance set at $p < 0.017$, Bonferroni's correction for 3 comparisons(Curtin & Schulz, 1998)). Since Delplanque et al. (2008) provided evidence for dissociation between subjective responses to odors as a function of pleasantness, we computed separate correlations between pleasant ($n = 45$) and unpleasant ($n = 15$) odors, and between appetent ($n = 20$) and inappetent ($n = 40$) odors (Figure 1). The middle of the visual analogue scale was used in order to group the odors in pleasant/unpleasant and appetent/inappetent odors. Pleasantness was related with intensity, as pleasantness decreased when intensity increased for unpleasant odors, whereas appetence and intensity ratings were independent. Pleasantness and arousal were positively correlated for pleasant odor. In contrast, no relationship was observed between appetence and arousal. Both pleasantness and appetence were positively correlated with familiarity for pleasant and appetent odors, but not for unpleasant and inappetent odors. Collectively, these results highlight the differences between the pleasantness and appetence features of odors as well as the value of using both evaluations in order to describe the sensory image of an odor.

➔ **Insert Figure 1**

Based on the evaluations of the 60 odors, we selected 30 odorants to create three categories of 10 odors each that were used in the Main Experiment (Table 1). First of all, we used rating of edibility in order to conclude whether each odor referred to a Food or a non-Food odor. Then, within the Food odors, we used the ratings of fattiness to distinguish the Fat and non-Fat food odors. Finally, within each of the three odor groups, we used the scores of the other dimensions (intensity, familiarity, arousal, sweetness, typicality) and tried different combinations of 10 odors until we found the one matching the most our criteria. Results of the evaluation of the 9 attributes are presented (only for those 30 selected odors) in Figure 2. The scores obtained for each odor attribute were submitted to ANOVA with *odor category* (Fat, NFat, NFood) as the fixed factor and *subject* and *odor(odor category)* as the random factors. As expected, the three odor categories differed in terms of edibility [$F(2,27) = 109.21$, $p < 0.001$] with food (Fat, NFat) odors being more edible than NFood odors. They differed in terms of fattiness [$F(2,27) = 158.89$, $p < 0.0001$] because Fat odors were rated as evoking fattier sensations than NFat and NFood odors. This selection led to homogeneous groups of odors in terms of intensity, arousal, sweetness, familiarity and typicality [$F(2,27)$'s < 3.01, p's > 0.05].

Beside the selection criteria, appetence and pleasantness were used to describe the liking and wanting dimensions, respectively. Not surprisingly, the three odor categories differed in terms of appetence [$F(2,27) = 31.93$, $p < 0.001$], food odors being more appetent than NFood odors. The three odor categories also slightly differed in terms of pleasantness [$F(2,27) = 5.39$, $p < 0.05$], with NFat odors being considered more pleasant than Fat or NFood odors.

➔ **Insert Table 1 and Figure 2**

3. Main Experiment

3.1. Objective and design

The Main Experiment aimed to test the influence of internal state (hunger or satiety) on the reward value of odors from three different categories: non-food odors (NFood), fatty food odors (Fat) and non-fat food odors (NFat). Two groups of subjects were tested twice. One group was tested in the hungry state and then in the satiated state after a calibrated lunch (group HS, for Hungry-Satiated), and the other group was tested only in the hungry state, once before and once after a rest period (group HH, for Hungry-Hungry). This paradigm enabled the effect of the internal state to be tested while controlling for the impact of test repetition. To assess the reward value of the odors, pleasantness (liking) and appetence (wanting) evaluations were compared for their ability to reveal alliesthesia.

3.2. Materials and Methods

3.2.1. Participants

The HS group included 38 volunteers (age range, 18 to 35 years; mean, 24.9 years; 21 females) and the HH group included 34 volunteers (age range, 18 to 33 years; mean, 24.7 years; 19 females). The recruitment, selection criteria and instructions were identical to those used in the Preliminary Experiment. The investigations were performed in accordance with the Declaration of Helsinki. Participants received written and oral information about the study and signed a consent form. They received a 20 euro compensation.

The subject's body mass index (BMI) was computed from declared weight and height in order to control for its potential confounding effect (Brondel et al., 2007) (HS: 23.84, s.e. = 0.82; HH: 23.07, s.e. = 0.52 kg/m^2). Both groups were similar in terms of age (unpaired two-tailed, $t = 0.19$, $p > 0.05$), gender (Chi-square, $\chi^2 = 0.51$, $p > 0.05$) and BMI (unpaired two-tailed, $t = 0.77$, $p > 0.05$).

3.2.2. Odorants

Three sets of 10 odors from different categories (Fat, NFat, NFood) were selected from the Preliminary Experiment (Table 1). The concentrations of three of the solutions were increased (mint, 8 ml/l; tobacco, 20 g/l; glue, 1 g/l) in order to achieve a subjective intensity similar to those of the other odors. In fact, during the Preliminary Experiment, the 3 aforementioned odors obtained low intensity scores (mint, 4.30; tobacco, 2.87; glue, 3.98) in comparison to other solutions (mean intensity score for the 30 odors was 6.45, s.e. = 0.08). After adjustment of the concentration of those odorants, intensity ratings collected during the Main Experiment showed intensity scores of 5.77 for mint, 4.58 for tobacco and 5.64 for glue, which was in accordance with the intensity of other solutions (mean intensity score for the 30 odors was 6.51, s.e. = 0.05).

3.2.3. Meal

The calibrated meal presented to the HS group was composed of 150 g of grated carrots with salad dressing (160.5 kcal; protein, 1.7 g; carbohydrate, 14.1 g; lipid, 10.8 g), 270 g of 'hachis parmentier' (a mix of mashed potatoes and minced beef meat; 378

kcal; protein, 15.9 g; carbohydrate, 24.0 g; lipid, 24.3 g), 30 g of 'camembert' (cheese; 156 kcal; protein, 2.7 g; carbohydrate, 17.1 g; lipid, 8.5 g), 80 g of chocolate mousse topped with whipped cream (79.9 kcal; protein, 6.3 g; carbohydrate, 0.2 g; lipid, 6.0 g) and 40 g of bread (baguette; 113.2 kcal; protein, 3.4 g; carbohydrate, 23.6 g; lipid, 0.8 g). The meal did not include ingredients that could be associated with olfactory stimuli used in the evaluation session to rule out the sensory-specific satiety phenomenon (Rolls et al., 1981). Subjects were instructed to eat as much as they desired. They were allowed to ask for extra food portions. The meal was served in a separate room from the testing room.

3.2.4. Experimental procedure

The experiment was composed of two 45-min sessions (1 and 2) of odor evaluation with a 30-min lunch (HS) or rest (HH) between the two sessions, and it lasted 2 hours in total (from 12:00 to 14:00). During the rest time corresponding to the lunch time for the HS group, the HH subjects were instructed to relax in a separate room.

Subjects were presented with the 30 odorants following a pseudo-randomized order (no more than three consecutive odorants from the same category). For each odorant, subjects were instructed to smell the odorant and to rate five odor attributes on visual analogue scales: pleasantness, appetence, intensity, fattiness and sweetness. The last three attributes were selected to test for the selectivity of the effect of the internal state on the odor's reward value. The order of the rating scales was identical for all odorants and subjects (intensity, pleasantness and appetence, fattiness and sweetness). The presentation order of the odors was varied across sessions.

The subject's internal state was evaluated through their desire to eat at the beginning and end of the two sessions using a visual analogue scale (Question, "Do you currently want to eat?"; anchors, "I don't want to eat at all" and "I really want to eat"). The meal was evaluated by the HS group with respect to both quality and quantity before the beginning of the second evaluation session using three questions: "How much did you like the meal?" (anchors "I didn't like it at all" and "I liked it very much"), "Food quantities presented during the meal were" (anchors "Too little," "As needed" and "Too big"), and "In comparison to your usual meal, this meal was" (anchors "Not hearty enough," "Hearty enough" and "Too hearty").

3.2.5. Data analysis

Responses on the 12-cm visual analogue scales were converted into scores varying from 0 to 10. Data analyses were conducted using the same tools and the same general procedure as for the Preliminary Experiment. All results reported here were significant at the 0.05 level unless otherwise noted. Means are given with standard error (s.e.).

3.3. Results

3.3.1. Desire to eat

Scores obtained for desire to eat were submitted to an ANOVA with *group* (HS, HH), *session* (1, 2) and *moment(session)* (beginning, end) as fixed factors and *subject(group)* as a random factor. The ANOVA revealed a significant main effect of *group* [$F(1,70) = 52.3$, $p < 0.001$], of *session* [$F(1,70) = 90.8$, $p < 0.001$] and a significant interaction between *group* and *session* [$F(1, 70) = 309.8$, $p < 0.001$]. *Post-hoc* analyses showed that the *session* effect was significant but reversed in the two groups. Desire to eat decreased after lunch for the HS group (Session 1: 6.85, s.e. = 0.28; Session 2: 0.64, s.e. = 0.15), whereas it increased after a rest period for the HH group (Session 1: 5.88, s.e. = 0.31; Session 2: 7.73, s.e. = 0.32). Moreover, desire to eat was higher in the HH than the HS group in Session 2, whereas no significant difference between groups was observed in Session 1. These results showed that the internal state was accurately manipulated during the experiment. The ANOVA also indicated a significant main effect of *moment(session)* [$F(2,140) = 27.5$, $p < 0.001$]. Desire to eat increased from the beginning to the end of the first session (beginning: 5.60, s.e. = 0.28; end: 7.19, s.e. = 0.29), whereas no change was observed in the second session (beginning: 3.85, s.e. = 0.48; end: 4.12, s.e. = 0.48). No significant interaction between *group* and *moment(session)* was observed.

3.3.2. Meal evaluation

With regard to meal evaluation, we considered the middle of the scale (score of 5) as corresponding to an average level of satisfaction. Two-tailed paired *t*-tests were performed in order to evaluate whether or not the meal evaluations were different from the average satisfaction level. The results showed that HS subjects rated the meal as being pleasant (7.46, s.e. = 0.34; $t = 7.31$, $p < 0.001$), of satisfactory quantity (5.21, s.e. = 0.16; $t = 1.28$, $p > 0.05$) and as hearty as usual (5.73, s.e. = 0.39; $t = 1.89$, $p > 0.05$), proving the adequacy of the meal.

3.3.3. Odor evaluation

In order to check whether the two groups had identical odor perceptions in Session 1, scores from this first session were submitted to an ANOVA with *group* and *odor category* as fixed factors, and *subject(group)* and *odor(odor category)* as random factors. No significant *group* effect was observed for any of the attributes (pleasantness, appetence, intensity, fattiness and sweetness), indicating that the two groups were comparable (p's > 0.05).

In order to assess the influence of the internal state on odor evaluation, the scores were then submitted to ANOVA with *session* and *odor category* as fixed factors, and *subject* and *odor(odor category)* as random factors. Separate analyses were run for each attribute and each group. No significant *session* effect or significant *session* × *odor category* interaction was observed in the HH group for pleasantness or appetence, thus ruling out any impact of mere replication of measurement on odor reward value (Figure 3). A significant *session* effect and a significant *session* × *odor category* interaction was observed in the HS group both for pleasantness [*session*: $F(1,27) = 13.50$, $p < 0.001$; *session* × *odor category*: $F(2,27) = 5.87$, $p < 0.01$] and for appetence [*session*: $F(1,27) = 62.08$, $p < 0.001$; *session* × *odor category*: $F(2,27) = 7.89$, $p < 0.01$]. *Post-hoc* analyses revealed that the HS group judged both Fat and NFat odors as less pleasant and less appetent in Session 2 (when satiated) than in Session 1 (when hungry), whereas no such decrease was observed for NFood odors (Figure 3).

With the aim of comparing the effect of the internal state on the pleasantness and appetence evaluations in the HS group, an ANOVA was performed on the difference between session scores with *evaluation* (pleasantness, appetence) and *odor category* as fixed factors, and *subject* and *odor(odor category)* as random factors. This analysis showed a significant *evaluation* effect [$F(1,27) = 78.75$, $p < 0.001$], a significant *odor category* effect [$F(2,27) = 7.90$, $p < 0.01$] and a significant *evaluation* × *odor category* effect [$F(2,27) = 4.82$, $p < 0.05$]. *Post-hoc* analyses revealed that the decrease in appetence between Session 2 and Session 1 (-1.02, s.e. = 0.08) was higher than the decrease in pleasantness (-0.27, s.e. = 0.06). Moreover, the decrease in appetence between Session 1 and Session 2 was higher for Fat odors (-1.65, s.e. = 0.15) than for NFat odors (-1.04, s.e. = 0.14), which in turn was higher than that for NFood odors (-

0.38, s.e. = 0.11). However, the decrease in pleasantness was similar for Fat odors (-0.58, s.e. = 0.11) and NFat odors (-0.28, s.e. = 0.10), with both being higher than that of NFood odors (0.04, s.e. = 0.11).

➔ **Insert Figure 3**

Finally, an ANOVA with *session* and *odor category* as fixed factors and *subject* and *odor(odor category)* as random factors revealed in both groups a significant effect of *session* on sweetness [group HH: $F(1,27) = 19.16$, $p < 0.001$; group HS: $F(1,27) = 14.98$, $p < 0.001$] and on intensity [group HH: $F(1,27) = 13.12$, $p < 0.001$; group HS: $F(1,27) = 32.67$, $p < 0.001$], with odors being evaluated as more intense but less sweet in Session 2 than in Session 1. No such effect was observed for fattiness.

4. Discussion

This study aimed to evaluate the influence of the internal state (hungry vs. satiated) on the reward value of odors depending on whether or not they evoke food (Food *vs.* NFood odors), and among food odors, depending on whether or not they evoke a fatty food (Fat *vs.* NFat odors). The reward value was tested using both the liking (pleasantness) and wanting (appetence) evaluations, and their respective effectiveness to reveal alliesthesia was compared.

4.1. Alliesthesia is specific to food odors

The results of this study demonstrate the specificity of alliesthesia for food odors in comparison to NFood odors using olfactory stimuli. They confirm previous findings obtained using pictures as stimuli (Stoeckel et al., 2007). When the subject’s state changed from hunger to satiety after a hearty meal, food odors decreased in pleasantness (liking) and appetence (wanting), whereas no change was observed for NFood odors. It is also interesting to note that the internal state influenced the reward dimension only, because no group-specific influence of the internal state was observed on the intensity, sweetness or fattiness of odors.

4.2. Alliesthesia is greater for fatty food odors than non-fat food odors

Few authors have hypothesized that nutrient quality may influence the magnitude of alliesthesia for food-related stimuli. In a recent study, negative alliesthesia after meal consumption was observed for four energy-dense food odors (pizza, beef, bacon and cheese), whereas no effect was observed for odors from energy-diluted food (almonds, oranges and strawberries) (Jiang et al., 2008). Using a larger set of data, Finlayson et al. (2007) found that the reward value of a picture of food depends on the fattiness of the food, but no direct comparison between hungry and satiated states was performed to measure the amplitude of alliesthesia. Our results clearly demonstrate that although negative alliesthesia associated with satiety could be generalized to all categories of food-related odors, the magnitude of alliesthesia varied across odor categories. Alliesthesia for Fat food odors is greater than for NFat food odors, as shown by a greater decrease in appetence for Fat than for NFat food odors. The fattiness of an odor is therefore critical in the elaboration of the sensory image of a food item as a function of the internal state.

4.3. Alliesthesia is better revealed by assessment of appetence (wanting) than of pleasantness (liking)

In the Preliminary Experiment, we found that pleasantness and appetence had different profiles, as their relationship with the intensity and arousal attributes of odors differed. This is consistent with the results of the Main Experiment indicating that those attributes described alliesthesia differently from one another. Even if food odors were judged as both less pleasant and less appetent when satiated than when hungry, the decrease in appetence was higher than the decrease in pleasantness. Moreover, wanting evaluation, but not liking evaluation, revealed that alliesthesia was dependent on food odor category. In fact, the decrease in appetence was higher for fatty than for non-fat food odors, whereas the decrease in pleasantness was similar for both fatty and non-fat food odors. Thus, appetence evaluation seems to be more sensitive to the modulation of reward value of odors as a function of internal state and is better adapted to describing alliesthesia phenomenon.

Liking and wanting evaluations had been previously compared to help distinguish between affective and motivation responses to food items in a sensory-specific satiety phenomenon (Berridge, 1996; Berridge & Kringelbach, 2008). Under these conditions, it appears that these evaluations do not undergo the same evolutionary process over time with continuous exposure to the same food stimulus (Small et al., 2001; Zandstra et al., 2000). For example, in a study investigating changes in liking and wanting evaluations during the consumption of chocolate beyond satiety, the responses showed that wanting decreased much more rapidly than did liking (Small et al., 2001). Recently, the liking and wanting components of a reward were also dissociated in paradigms where alliesthesia was examined after *ad libitum* meal consumption, and even though they were not directly compared, the wanting scores seemed to decrease more than the liking scores (Finlayson et al., 2008; Jiang et al., 2008).

4.4. The confounding effect of familiarity on the evaluation of odor intensity

In the current study, all odors were evaluated as more intense in Session 2 than in Session 1. In contrast, no modification of fattiness ratings of the odor was observed.

The fact that this modification of intensity was observed regardless of odor group suggests that it was not related to the internal state, but to the repetition of the evaluations. In Session 2, participants evaluated odors they had already evaluated one hour ago, during Session 1. Odors were thus more familiar in Session 2 than in Session 1. It is precisely well established that familiarity and intensity ratings are highly correlated (Distel et al., 1999; Royet et al., 1999). The confounding effect of familiarity could thus explain the higher intensity ratings in Session 2, when odors were smelt for the second time, than in Session1, when odors were smelt for the first time.

4.5. Conclusions

This study enabled a better characterization of the variations in the reward value of odors as a function of internal state. Using a large set of data and a robust paradigm, it showed that alliesthesia is specific to food odors and that it is more pronounced with odors that evoke fatty foods than with odors that evoke non-fat foods. Our findings also allow for the distinction between liking (pleasantness) and wanting (appetence) according to their efficiency at reflecting the phenomenon of alliesthesia. The wanting evaluation is more sensitive than the liking evaluation for describing an acute reward modulation process, and it allows for the definition of a more comprehensive pattern of alliesthesia based on odor category.

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Table 1. Odorants selected for the main experiment.

Odors	Odor quality	Label from company	Diluent	Conc.
Fat	*Bacon*	Bacon	MO	5 g/l
	Biscuit	Biscuit aroma	MO	10 ml/l
	Butter	Melted butter aroma	MO	20 ml/l
	Butter caramel	Butter caramel aroma	DW	40 g/l
	Liver pâté	Liver pâté	DW	1.5 g/l
	Roasted chicken	Roasted chicken	MO	0.8 ml/l
	Sesame	Pure sesame oil	MO	10 ml/l
	Sour cream	Sour cream aroma	DW	12 g/l
	Spicy sausage	Spicy sausage	MO	4 g/l
	Tomato coulis	Tomato coulis aroma	MO	1 ml/l
NFat	*Apple*	Granny Smith apple	MO	2 ml/l
	Asparagus	Asparagus aroma	DW	0.4 g/l
	Banana	Isoamyl acetate	MO	0.4 ml/l
	Dill	Dill EO	MO	2.5 ml/l
	Grapefruit	Grapefruit zest EO	MO	2 ml/l
	Mandarin	Italian mandarin EO	MO	2.5 ml/l
	Mango	Mango	MO	0.1 ml/l
	Mint	Green mint aroma	MO	2 ml/l
	Thyme	Red thymol thyme EO	MO	1.5 ml/l
	Watermelon	Watermelon aroma	MO	10 ml/l
NFood	*Camphor*	Natural camphor	MO	5 g/l
	Cologne Water	Cologne Water (amber touch)	DW	20 ml/l
	Glue	Acetanisol	MO	0.2 g/l
	Jasmine	Jasmine absolute EO	MO	0.5 ml/l
	Lavender	Real lavender flower EO	MO	0.5 ml/l
	Leather	Leather	MO	1.5 ml/l
	Mouth wash	Methyl salicylate	MO	0.4 ml/l
	Oil paint	Rosemarel	MO	2 ml/l
	Pine	Bornyl acetate	MO	6 ml/l
	Tobacco	Original red	MO	10 g/l

Abbreviations: Conc., concentration; DW, distilled water; EO, essential oil; MO, mineral oil.

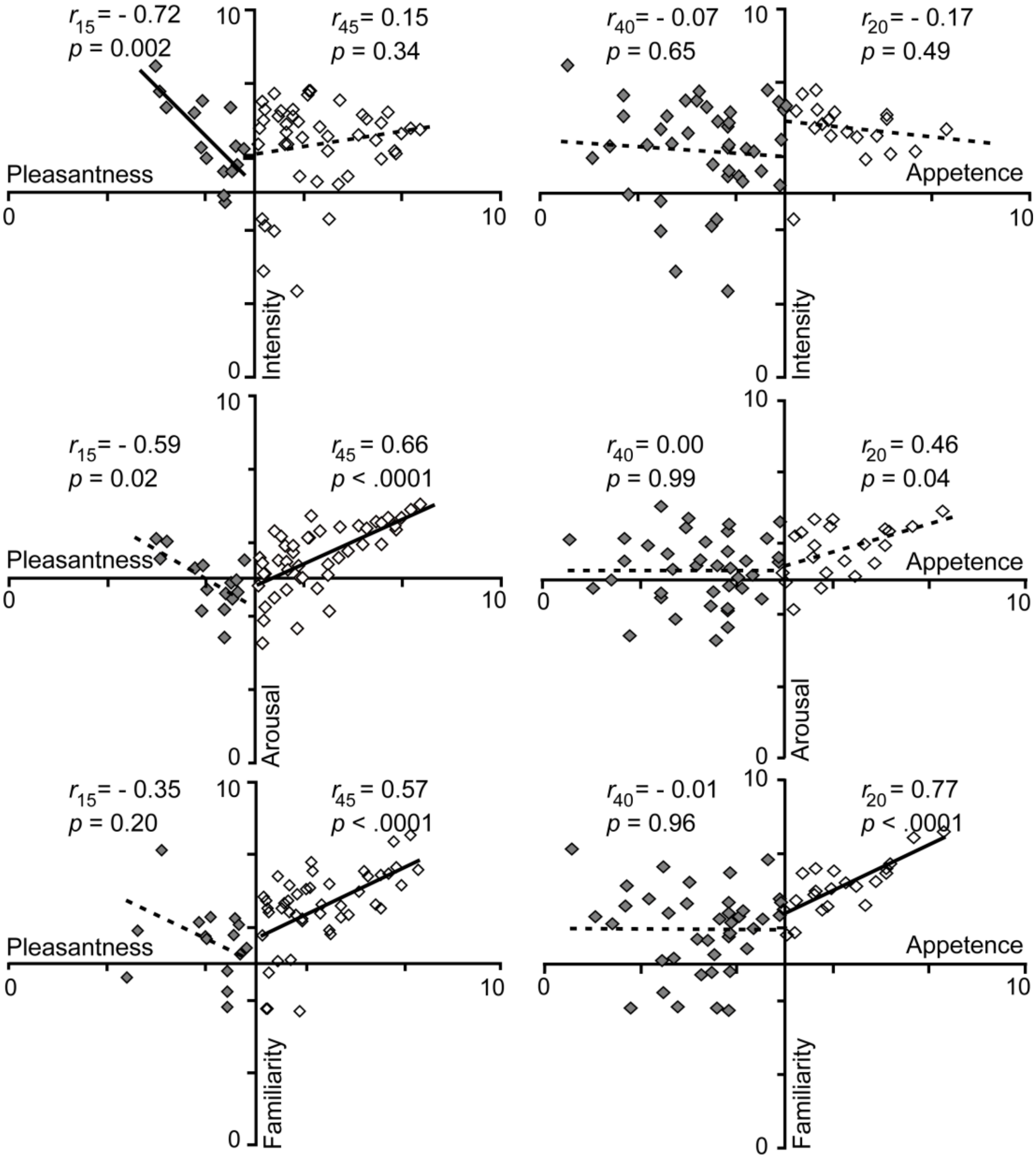
Figure legends

Fig. 1. Relationship between evaluations of the 60 odor attributes when the odors were distinguished based on their positive (white diamond) or negative (grey diamond) valence or appetence (for each odor, individual scores were averaged). *r*, Pearson's coefficient of correlation; *p*, p-values; Full line when significant, dashed line when non-significant.

Fig. 2. Mean evaluation scores of the nine attributes in the three odor categories selected for the Main Experiment. Means associated with the same letter are not significantly different according to *post-hoc* analyses ($p > 0.05$). Error bars represent standard error of the mean.

Fig. 3. Mean pleasantness and appetence evaluations of the three categories of odors (Fat, NFat, NFood) depending on group (HS, Hungry-Satiated, and HH, Hungry-Hungry) and session. For each group, means associated with the same letter are not significantly different according to *post-hoc* analyses ($p > 0.05$). Error bars represent standard error of the mean.

Figure 1



r15= - 0.72
p = 0.002
r45= 0.15
p = 0.34
r40= - 0.07
p = 0.65
r20= - 0.17
p = 0.49
Pleasantness
Appetence
Intensity
r15= - 0.59
p = 0.02
r45= 0.66
p < .0001
r40= 0.00
p = 0.99
r20= 0.46
p = 0.04
Arousal
r15= - 0.35
p = 0.20
r45= 0.57
p < .0001
r40= - 0.01
p = 0.96
r20= 0.77
p < .0001
Familiarity
0
10

Figure 2

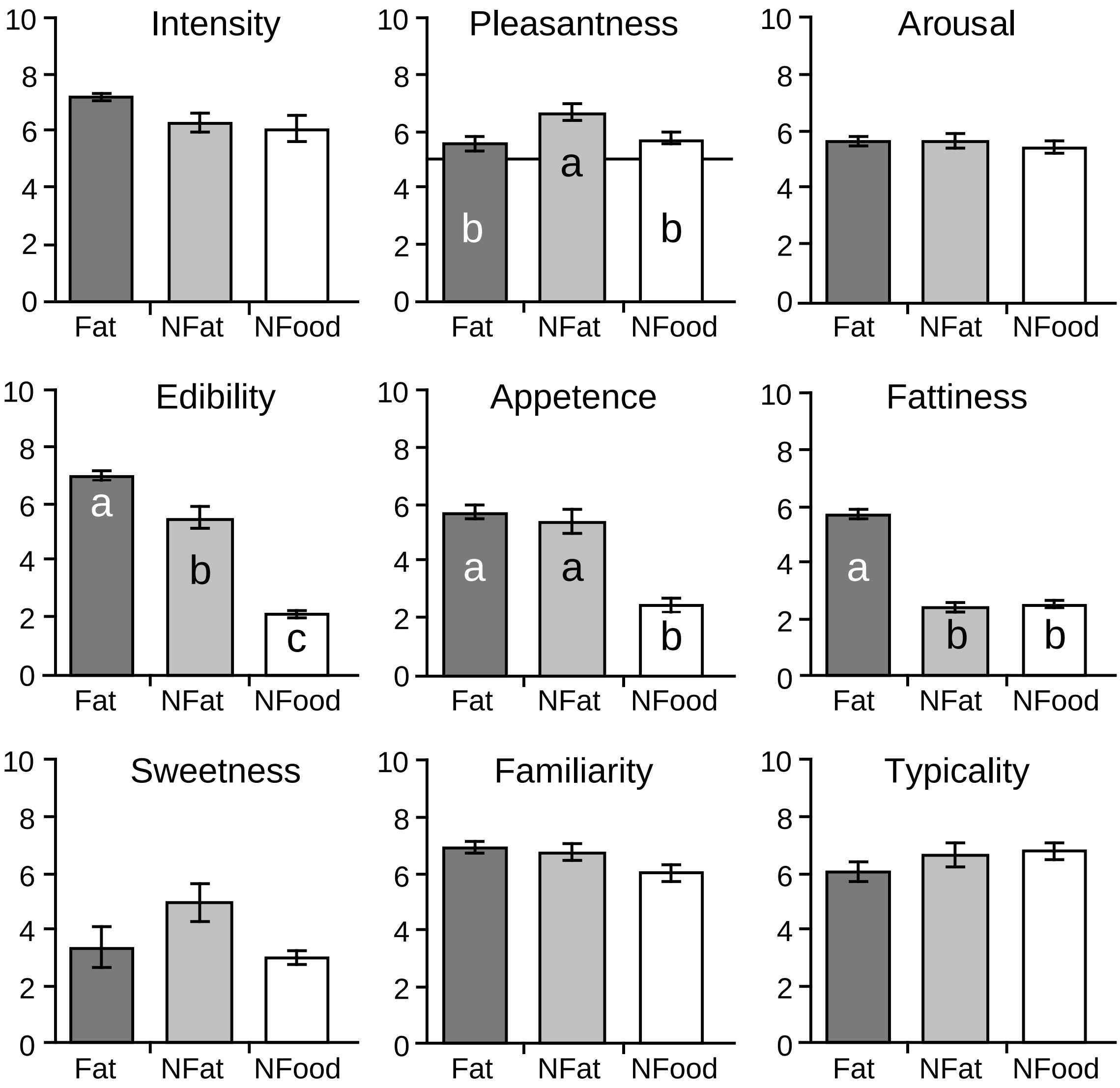
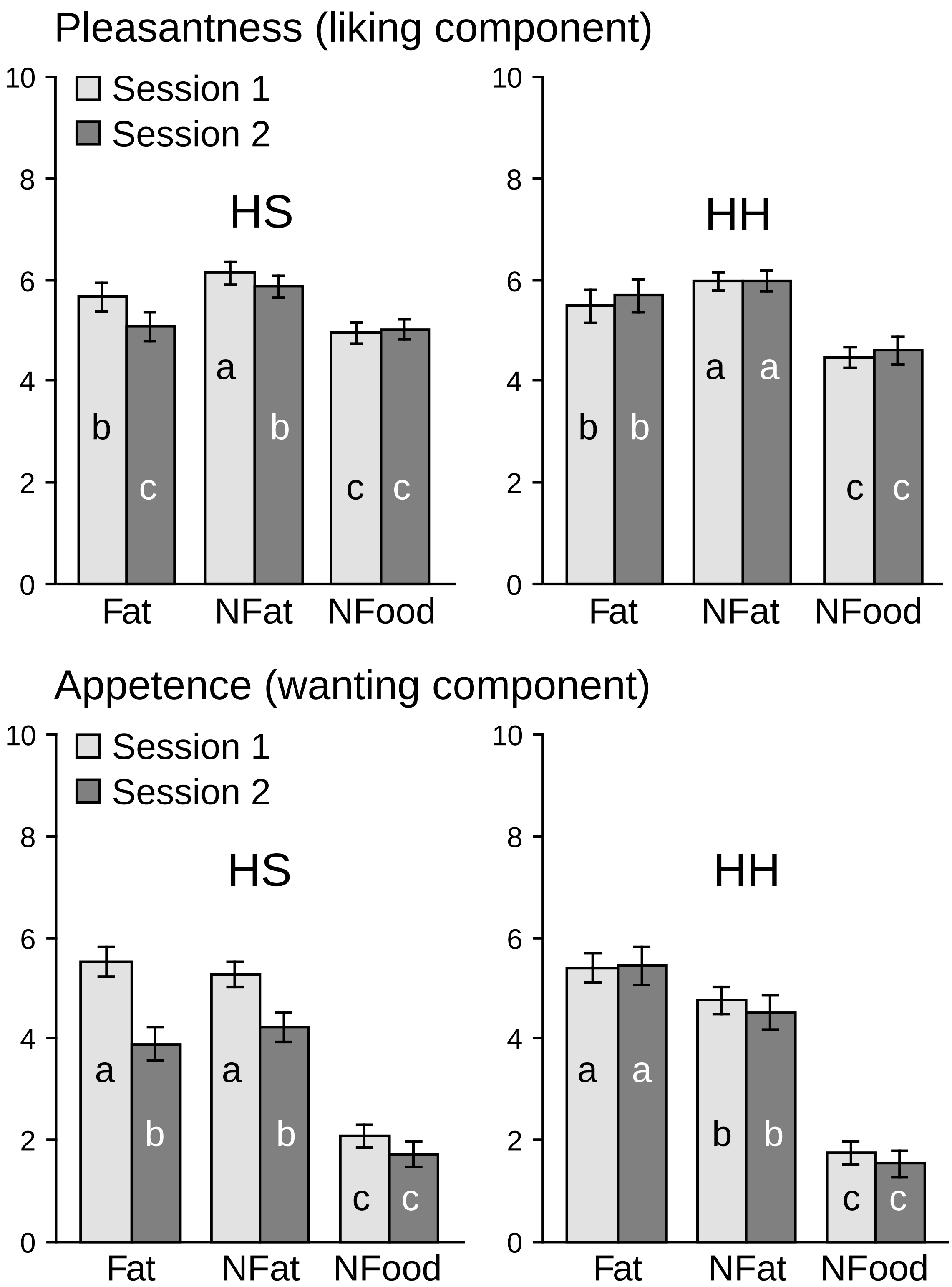

Intensity
Pleasantness
Arousal
Edibility
Appetence
Fattiness
Sweetness
Familiarity
Typicality
0
2
4
6
8
10
Fat
NFat
NFood
a
b
c

Figure 3


Pleasantness (liking component)
Session 1
Session 2
HS
HH
10
8
6
4
2
0
a
b
c
Fat
NFat
NFood
Appetence (wanting component)
Session 1
Session 2
HS
HH
10
8
6
4
2
0
a
b
c
Fat
NFat
NFood