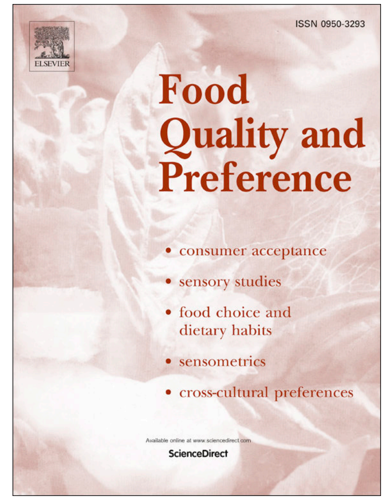
The influence of stimulus concentration and odor intensity on relaxing and stimulating perceived properties of odors

Alessia Baccarani, Gérard Brand, Catherine Dacremont, Dominique Valentin, Renaud Brochard

Journal Pre-proofs



The Influence of Stimulus Concentration and Odor Intensity on Relaxing and Stimulating Perceived Properties of Odors

Alessia Baccarani, Gérard Brand, Catherine Dacremont, Dominique Valentin, Renaud Brochard

PII: S0950-3293(20)30299-8
DOI: https://doi.org/10.1016/j.foodqual.2020.104030
Reference: FQAP 104030

To appear in: *Food Quality and Preference*

Received Date: 21 December 2019
Revised Date: 30 May 2020
Accepted Date: 11 July 2020

Please cite this article as: Baccarani, A., Brand, G., Dacremont, C., Valentin, D., Brochard, R., The Influence of Stimulus Concentration and Odor Intensity on Relaxing and Stimulating Perceived Properties of Odors, *Food Quality and Preference* (2020), doi: https://doi.org/10.1016/j.foodqual.2020.104030

The Influence of Stimulus Concentration and Odor Intensity on Relaxing and Stimulating Perceived Properties of Odors

Alessia Baccarani[a]*, Gérard Brand[a], Catherine Dacremont[a], Dominique Valentin[a], and Renaud Brochard[a]

[a]*Centre des Sciences du Goût et de l'Alimentation, AgroSup Dijon, CNRS, INRAE, Université Bourgogne Franche-Comté, F-21000 Dijon, France.*

*Corresponding author:

Alessia Baccarani - alessia.baccarani@u-bourgogne.fr

ORCID identifier: 0000-0001-7033-6501

Université Bourgogne Franche-Comté, France

Centre des Sciences du Goût et de l'Alimentation,

9 E Boulevard Jeanne d'Arc, 21000 Dijon

Co-authors contact:

Gérard Brand - gerard.brand@univ-fcomte.fr

Catherine Dacremont - Catherine.Dacremont@u-bourgogne.fr

Dominique Valentin - Dominique.Valentin@u-bourgogne.fr

Renaud Brochard - renaud.brochard@u-bourgogne.fr

Abstract

It is generally assumed that intensity can be used as a proxy of the arousing properties of odors: the more concentrated an odorant, the more intense an odor and the more stimulating and the less relaxing the odor. The aim of the present study was thus to investigate the relationship between relaxing and stimulating properties of odors when judged on two independent scales, for different levels of stimulus concentration. Thirty-three volunteers judged relaxing, stimulating, pleasantness, familiarity and intensity properties of four odors, namely strawberry, lavender, coffee, and lemon, at five concentrations. Our findings show that for all odors, higher stimulus concentration is associated with higher perceived intensity and higher stimulating judgments whereas it was not associated with lower relaxing judgments. On the contrary, lavender and strawberry were also judged more relaxing when stimulus concentration increased whereas coffee and lemon relaxing properties remained the same overall whatever the concentration. Odor familiarity increased with stimuli concentration as well as pleasantness (with the exception of coffee odor). Our results underline the need to use two separate unipolar scales when assessing the relaxing and stimulating properties of odors in self-report questionnaires. They also question the suitability of the commonly used bidimensional framework (valence vs. arousal) to describe olfactory emotions.

Keywords: arousal, odors, relaxing, stimulating, stimulus concentration

1. Introduction

The use of scents to modulate mood is a common practice that seems to have always accompanied humans. However, it was not until the last two decades that olfactory research started to bring evidence supporting an emotional impact of scents, such as relaxing or stimulating effects on physiology and behavior (Diego et al., 1998; Ghiasi, Bagheri, & Haseli, 2019; Lehrner, Marwinski, Lehr, Johren, & Deecke, 2005; Lemercier-Talbot et al., 2019; Motomura, Sakurai, & Yotsuya, 2001; Sayorwan et al., 2012; Sayowan, Siripornpanich, Hongratanaworakit, Kotchabhakdi, & Ruangrungsi, 2013; for reviews see Herz, 2009 and Hongratanaworakit, 2004). Perceived properties of odors and odor-elicited emotions are commonly assessed with self-report questionnaires assessing valence and arousal dimensions (in particular in food-related contexts, e.g. Jaeger, Spinelli, Ares, & Monteleone, 2018; for a recent review see Kaneko, Toet, Brouwer, Kallen, & van Erp, 2018). Recent studies showed that relaxing and stimulating properties are fundamental features of olfactory-induced emotions (Chrea et al., 2009; Delplanque et al., 2012; Ferdenzi et al., 2011; Lemercier-Talbot et al., 2019; Porcherot et al., 2010). These relaxing and stimulating properties of olfactory stimulus play an important role in daily activities. For instance, food aromas and flavors are part of our daily sensory experiences, and are known to be relaxing and stimulating (Jaeger et al., 2018; Kaneko et al., 2018; Köster & Mojet, 2015; Piqueras-Fiszman & Jaeger, 2014; Toet et al., 2018).

Discrepancies in olfactory relaxing and stimulating properties

Conflicting findings regarding activation properties of odors have been reported in the literature, with the very same odor having been described either relaxing or stimulating depending on the study (Atsumi & Tonosaki, 2007; Jin, Haviland-jones, Simon, & Tepper, 2018; Kiecolt-Glaser et al., 2008; Kikuchi, Yamaguchi, Tanida, Abe, & Uenoyama, 1992; Komiya, Takeuchi, & Harada, 2006; Lehrner, Eckersberger, Walla, Pötsch, & Deecke, 2000;

Manley, 1993; Moss, Hewitt, Moss, & Wesnes, 2008; Porcherot et al., 2010; Warren & Warrenburg, 1993). For instance, the odor of lemon has been found stimulating in some studies which used physiological measurements (Kiecolt-Glaser et al., 2008; Kikuchi et al., 1992), whereas others highlighted a relaxing effect of this odor (e.g., Manley, 1993, see also Komiya, Takeuchi, & Harada, 2006, for an anti-stress effect of lemon in behavioral tasks in mice). A similar discrepancy has been reported for both rosemary and nutmeg, which have been found to be relaxing based on physiological measurements of arousal (Atsumi & Tonosaki, 2007; Warren, 1987; Warren & Warrenburg, 1993), but stimulating based on performance in cognitive tasks (i.e., an increase in memory performance for rosemary, Moss et al., 2008) or even failed to show any relaxing or stimulating effect (i.e., for nutmeg, Warm, Dember, & Parasuramen, 1991; Warren & Warrenburg, 1993). Although these mixed evidences might stem from distinct methodological approaches (e.g., behavioral, physiological, etc.; see Herz, 2009; Sowndhararajan & Kim, 2016), discrepancies simply occur in subjective judgments. For example, peppermint is judged as stimulating in some studies (Moss et al., 2008; Warm et al., 1991) but scored low on an “activation scale” in others (Dalton, Maute, Oshida, Hikichi, & Izumi, 2008; Sellaro, van Dijk, Rossi Paccani, Hommel, & Colzato, 2015). The olfactory stimulus used might be at the root of such inconsistencies across studies. For instance, it has been shown that different flavors of strawberry can lead to distinct perceived emotional properties (Porcherot et al., 2010). These authors examined the emotional ratings of six different strawberry-flavored products, i.e., fruity strawberry, floral strawberry, cooked strawberry, creamy strawberry, green strawberry and wild strawberry solutions. Their analysis revealed a significant Product × Emotional Dimension interaction, with products being rated differentially depending on the emotions. Higher scores were given to the ‘‘Disgusted – Irritated – Unpleasantly surprised” dimension for the ‘‘green” and ‘‘floral” strawberry flavors than for the ‘‘fruity” and ‘‘cooked” strawberry flavors.

Beyond the aforementioned methodological and measurement issues, discrepancies may also emerge because activation properties of odors have been considered within different theoretical frameworks (e.g., Herz, 2009; Kaeppler & Mueller, 2013; Sowndhararajan & Kim, 2016). The circumplex model of affect (Feldman Barrett & Russell, 1998; Russell, 1980), is an influential model of emotion broadly used within the olfactory domain (Anderson et al., 2003; Bensafi et al., 2002; Chebat & Michon, 2003; Herz, Schankler, & Beland, 2004; Heuberger, Hongratanaworakit, Böhm, Weber, & Buchbauer, 2001; Jönsson, Olsson, & Olsson, 2005; Pössel, Ahrens, & Hautzinger, 2005; Schifferstein & Tanudjaja, 2004; Warrenburg, 2005). In this model, valence and arousal are thought of as two independent dimensions of emotions. Valence reflects the pleasant-unpleasant properties of emotional stimuli, whereas emotional arousal reflects activating-deactivating properties. In a nutshell, this means that the more relaxing an odor the less stimulating it is. Although both dimensions are essential parts of the model, valence was typically conceived as the key function in olfaction, and for some authors was even seen as the "primary axis of odor perception" (He, de Wijk, de Graaf, & Boesveldt, 2016; Knaapila et al., 2017; Yeshurun & Sobel, 2010). Accordingly, valence certainly benefited of more interest from the research community than the arousal dimension.

It has been argued however that such a bidimensional grid is unable to fully account for the complexity of odor-elicited emotions, stressing the necessity to rely on an olfactory-specific approach (Chrea et al., 2009; Porcherot et al., 2010). These authors proposed additional dimensions to better represent the semantic affective space elicited by odors and six main emotional dimensions have been pointed out, i.e., "Happiness-Well-being", "Awe-Sensuality", "Disgust-Irritation", "Sensory pleasure", "Soothing-Peacefulness", and

"Energizing-Cooling" (Chrea et al., 2009). The most discriminative terms of the Soothing-Peacefulness dimension were "relaxed", "soothed"," serene", "reinsure" and "light" and those of the Energizing-Cooling dimension were "stimulated", "invigorated", "clean", "shivering", "energetic", "refreshed, "revitalized". The description of "Soothing-Peacefulness" and "Energizing-Cooling" as separate emotional dimensions leads to the possibility that Russell's arousal dimension might be thought of as a mixture of two independent dimensions rather than reflecting a single continuum ranging from relaxing to stimulating properties. So far however, only a few studies were designed to assess relaxing and stimulating properties of odors at the same time on two independent scales (e.g., strawberry, Porcherot et al., 2010; lily of the valley and hyacinth, Warren & Warrenburg, 1993; Warrenburg, 2002, 2005). Interestingly, a strong positive correlation (r = 0.83) has been reported between soothing and energizing ratings for a large set of odors (Chrea et al., 2009), whereas a negative relationship would have been expected according to the unidimensional conception of relaxing/stimulating odor properties.

The role of odorant concentration and odor intensity in olfactory perceived activation properties

First of all, it is important to note that the olfactory stimulus is generally referred to as the « odorant » whereas the percept is called the « odor » (Hudson, 2000; Smeets & Dijksterhuis, 2014). In this view, concentration refers to the objective odorant's quantity of chemical compounds, whilst intensity refers to the perceived property of an odor. Considering the large interindividual variability in smell sensitivity and detection thresholds (Chastrette, 2002; Doty & Laing, 2015), studies examining olfactory emotions are typically run at perceived iso-intensity to allow for comparisons, thus with only one concentration per odorant. However, the concentration of an odorant has been proven to bear a crucial influence on the emotion elicited (Distel et al., 1999; Doty, 1975; Gross-isseroff & Lancet, 1988;

Henion, 1971; Moskowitz, Dravnieks, & Klarman, 1976; see Kaeppler & Mueller, 2013; Rouby, Pouliot, & Bensafi, 2009 for reviews), and odorant concentration and odor hedonic valence can co-vary in a complex manner (Rouby et al., 2009). Some odorants show positive correlations between concentration and valence ratings (i.e., the more it is concentrated the more it is judged pleasant, e.g., methyl salicylate, Doty, 1975), whereas others show a negative correlation (i.e., the more it is concentrated the more it is judged unpleasant, e.g., furfural), or a rise followed by a drop (e.g., benzyl acetate, Doty, 1975), and in some cases concentration has no impact on hedonic valence (e.g., vanillin remains pleasant whatever its concentration, Mower, Mair, & Engen, 1977).

By contrast with valence, the interaction between concentration and the activation properties might have been slightly overlooked. Previous studies have reported positive correlations between odor intensity and arousal ratings (Bensafi et al., 2002; Chrea et al., 2009), leading to the view that the perceived intensity could even be seen as a substitute for the arousal dimension of olfactory emotions (e.g., Anderson et al., 2003; Lewis, Critchley, Rotshtein, & Dolan, 2007; Winston, Gottfried, Kilner, & Dolan, 2005). However, conceptualizing odor intensity as a proxy of emotional arousal properties of an odor might be too simplistic considering that some odorants can be stimulating at very low concentrations, and even at subliminal levels as showed by implicit measure (e.g., low level of lavender essential oil enhances memory performance, Degel & Köster, 1999).

A recent study specifically investigated the relationship between the emotional perceived properties of an odor and the corresponding odorant concentration on subjective measures (Jin et al., 2018). Findings showed that the main emotion property (“mood signature method”) of an odor could change from low to medium-high odorant concentration, and even shift from “calm-relaxed” at low concentration to “exciting-energized” properties at mid-range concentration. This shift could be related to the pungency of the odorant at higher concentrations (Jin et al., 2018), and thus may be odorant-specific. These results are in line with prior studies showing direct relationship between a potential "arousal dimension" and odor perceived intensity. It is worth mentioning however that the use of forced-choice in the "mood signature method" led the participants to choose between potentially important emotional properties, thus meeting similar limitations as the bidimensional scales (assuming that an odor can be either relaxing or stimulating). Although such a method is relevant to identify dominant perceived emotion, it might be less suited to investigate the complexity and richness of emotions elicited by odors.

The purpose of the present study was thus to investigate the role of odorant concentration on the perceived relaxing and stimulating properties of odors (strawberry, lavender, coffee, and lemon), on two independent scales, in order to test potentially distinct effects of concentration. Previous studies assessing the role of concentration on stimulating and relaxing judgments have typically contrasted few concentrations (e.g., two concentrations, Jin et al., 2018; three concentrations, Kikuchi et al., 1992), thus preventing a fine-grained examination of the effect of odorant concentration on olfactory-perceived emotions. In the present study, we collected judgments for five levels of odorant concentration, with equivalent perceived intensity across odors at each level. According to bidimensional conceptions, we expect a negative relationship between stimulating and relaxing properties. In other words, high relaxing judgments should be accompanied by low stimulating judgments, and conversely. However, according to multidimensional conceptions, relaxing and stimulating properties of an odor might be judged independently. Henceforth, we expect either a positive relationship between relaxing and stimulating judgments or even no relation at all. A second goal of the present study was to determine whether the relationship between the activation properties and the odor intensity is straightforward as previously shown by studies using a bidimensional model. If so, the activation properties of odors should mirror the level of odorant concentrations, irrespective of their *a priori* relaxing or stimulating property. For instance, odors previously identified either as "stimulating" (i.e., coffee and lemon) or "relaxing" (i.e., strawberry and lavender) should nevertheless be found relaxing at lower odorant concentrations and stimulating at higher ones. Furthermore, in the present study, participants were presented with pleasant odors only, since valence interacts with intensity and could be a potential confounding variable. In addition, unpleasant odors with low level of arousal are quite rare since unpleasant odors are generally also arousing (Bensafi et al., 2002; Royet, Plailly, Delon-Martin, Kareken, & Segebarth, 2003; Sorokowska et al., 2016; Velasco, Balboa, Marmolejo-Ramos, & Spence, 2014). In addition, only aromas were used here in order to study a homogenous set of food-related odors since potential distinct mechanisms might underlie non-food-related stimuli (Iannilli et al., 2015; Zarzo, 2008). That being said, and as commonly done in the field, pleasantness and familiarity judgments were also collected to check for potential modulating effect of these factors.

2. Method

2.1. Pre-test: preselection of odorant concentrations

We selected coffee and lemon as stimulating odors, and strawberry and lavender as relaxing ones based on prior literature (Chrea et al., 2009; Guéguen & Petr, 2006; Lehrner et al., 2005; Porcherot et al., 2010) and pre-screening on the basis of judgments among a collection of 18 odors. Strawberry and lavender were considered to be the most relaxing among the18 odors presented at iso-intensity and lemon and coffee the most stimulating. Then, the present pre-test was run in order to determine for each of the four preselected odors the five concentrations to be used in the main experiment. During this pre-test, 24 concentrations for each odorant were prepared into 60 mL brown glass vials using a 2-fold serial dilutions method protocol (considering 0.5 factor dilution, the first vial contained a 50.000%v/v solution and the last one, the most diluted, a 5.961 10^{-6}%v/v solution). Coffee, lemon, strawberry and lavender odorants were prepared from artificial aromas selected from "*Le meilleur du che*f®" website: "Arôme café note Colombie, SELECTARÔME", 58 mL; "Arôme naturel citron, SELECTARÔME", 58 mL; "Arôme fraise, SELECTARÔME", 58 mL; "Arôme naturel lavande, SELECTARÔME", 58 mL. Two different solvents were used to obtain equivalent miscible solutions: strawberry and coffee were diluted in distillated water, and lavender and lemon were diluted in mineral oil (SIGMA-Aldrich, France). Eventually, 2 mL of the final solution were placed in a 60 mL brown glass vial on a fine-fiber dark absorbent (3x3 cm, 100% polypropylene fine fibers, 38 l/UV absorption, *DENSORB, "Universal" Light*, DENIOS®) in order to mask the color of the odorants.

The concentrations were selected with the constraint that the lowest concentration had to be detected by every participant. This was checked using a two-alternative forced choice test (2-AFC) with nine participants. They performed three consecutive 2-AFC tests (one blank versus one concentration in random order) for each concentration, concentrations being presented in an increasing order. The participant had to give three correct answers for two successive concentrations before their psychophysical threshold was considered to be reached. The lowest concentration for each of the four odors that was detected by all nine participants was eventually selected. The four lowest concentrations, which were not perceived by all participants, were not used in the main experiment.

The next step was to select the final five odorant concentration levels for each odor. Each olfactory stimulus of a given level had to be perceived as equally intense. Twenty-eight participants (16 females) assessed the odor intensity of the 20 odorant concentrations (presented in Table S1 in supplementary material) for each odor on a 11-point Likert scale (from 0 = *not perceived at all* to 10 = *extremely intense*) in a 1-hour session. Olfactory stimuli were prepared following the same procedure, the 20 concentrations of each odorant were prepared into 60 mL brown glass vials following a factor-two dilution cascade (the first vial contained a 50.000 %v/v solution and the most diluted, a 9.537 10^{-5} %v/v solution, see Table S1 of the supplementary material). Participants sat in a quiet and well-ventilated room. They were given a reference point to anchor the highest intensity of the scale by initially presenting the highest odorant concentration for each odor. Presentation of odors and concentrations were both randomized. During this session, participants had no time constraint and could sniff the stimulus as much as they needed before ratings. Nevertheless, in order to minimize adaptation effects, participants were asked to wait at least a few seconds after their ratings, before switching to another stimulus, and to smell their own clothes between each sample. They could drink water as much as they needed but they were encouraged to drink after an odor judged particularly intense. They took a short break (a few minutes) every 10 stimuli and a longer break (at least 10 minutes) in the middle of the session.

In order to have each olfactory stimulus of a given concentration level perceived as equally intense across odors, a linear regression analysis was performed on mean intensity ratings for the 20 odorant concentrations of each odor (see Figure S1 and Figure S2 in supplementary material). It allowed for identifying odorant concentrations leading to five intensity levels evenly spread out on the intensity scale (see Table 1), i.e., 3.1 to 3.7 - 4.1 to 5.4 – 5.7 to 6.8 – 7.1 to 7.4 – 8.2 to 8.9. An illustration of the logarithmic evolution of the five concentrations in volume/volume percentage retained for each olfactory stimulus for the main experiment is provided in supplementary material (Figure S3).

We also assessed the perceived pungency of the odors, as it was recently suggested that it could influence relaxing and stimulating judgments, sometimes leading to a shift from relaxing/calming ratings at low concentration to exciting/energizing ratings at medium-high concentration (see Jin et al., 2018). Fifteen participants (8 males, 7 females, age mean = 21.68 ± 2.62 years) judged the pungency of each odor at the five concentrations retained on a 11-

point Likert scale (from 0 = *not pungent at all* to 10 = *very pungent*). Results showed that none of them was considered pungent/irritating at any concentration (all means for each stimulus were below 2).

2.2. Main experiment

2.2.1. Participants

Thirty-three volunteer young adults (22 females, 11 males, M_{age} = 22.42±1.56 years, age range: 19-25 years) were recruited. All subjects gave their informed consent prior to participation. Testing was conducted in accordance with the Declaration of Helsinki. All participants were free of head colds, and self-reported normal olfactory sensitivity.

2.2.2. Procedure

The experimental sessions took place in a quiet and well-ventilated sensory room equipped with individual booths (located in the Centre du Goût et de l'Alimentation CSGA, Dijon, France). The participants sat facing a computer screen on which instructions were delivered along the experiment using FIZZ software (Biosystèmes, Couternon, France). Olfactory stimuli confection followed the exact same procedure as in the pretest, which lead to the selection of 20 olfactory stimuli: four odors * five concentrations (see previous section). Each participant had to judge the five concentrations of a given odor, all placed in the same box, before switching to the next box (the next odor) in order to avoid sensory confusion emerging from odor mixing (Herz & von Clef, 2001). The odor presentation order (box order) was randomized as well as the concentration presentation order in each box. The rating of each olfactory stimulus was collected on five visual analog scales presented separately in a randomized order ranging from 0 to 10 (i.e., *not stimulating at all* to *very stimulating*; *not relaxing at all* to *very relaxing*; *very unpleasant* to *very pleasant*; *very soft* to *very intense*, *not familiar* to *very familiar*). The terms "relaxing" and "stimulating" were selected from the

Emotion and Odor Scale (EOS) in relation with relaxing and energizing feelings (Chrea et al., 2009) rather than with the positive additional labels of the Affect Grid (i.e., "excitement" and "relaxation"; Russell, Weiss, & Mendelsohn, 1989) which are not specific of olfactory-elicited emotions. A reference point for intensity judgment was given by presenting each of four odorants at their maximal concentration. Participants had no time constraint and could sniff the odorants as much as they needed before answering the questions. The time interval between each concentration corresponded to the time required to complete the five scales. In order to minimize adaptation effects, participants were asked to wait at least a few seconds after their ratings before switching to the next stimulus, and to smell their own clothes between each sample. They could drink as much water as they needed and were encouraged to drink after a judged particularly intense odor and to wait a bit longer.

2.2.3. Data analysis

A mixed design three-way analysis of variance (ANOVA) was conducted on intensity, relaxing, stimulating, pleasantness, and familiarity ratings with odor (Lemon, Coffee, Lavender and Strawberry), and concentration (C1-C5) as within-factors, and sex (male, female) as between-factor. Preliminary analyses indicated that there was no main effect of sex nor any interaction on any scale. Thus, this factor was not considered any further. Reported *p*-values in *Post-hoc* comparison tests were Bonferroni corrected.

3. Results

3.1. Analysis of intensity ratings as a function of odorant concentration

To ensure that each intensity level was perceived as iso-intense for the four odors we ran a repeated-measure two-way ANOVA on intensity ratings with odor (coffee, lemon, lavender, strawberry) and concentration (C1-C5) as within-factors (the means and standard deviations are presented in Table 2). As expected, the analysis yielded a main effect of concentration on intensity ratings $F(12, 384) = 2.091$, $p = .017$, partial $\eta^2 = .061$, indicating that perceived intensity increased with physical concentration for all odorants. Importantly for our purpose, there was no significant effect of odor nor interaction (all *p*s >.05), further indicating that each of the five levels of concentration were well matched in perceived intensity across odors.

3.2. Analysis of stimulating and relaxing ratings as a function of odorant concentration

3.2.1. Stimulating scale analysis

A repeated-measure two-way ANOVA was conducted on stimulating judgments with odor (coffee, lemon, lavender, strawberry) and concentration (C1-C5) as within-factors. This analysis showed a main effect of concentration on ratings, $F(4,128) = 84.757$, $p < .001$, partial $\eta^2 = .726$, indicating that stimulating judgments increased with concentration for all odors (see Figure 1), even for the odors considered as relaxing (i.e., lavender and strawberry). There was no main effect of odor on stimulating judgments ($F[3,96] = 1.425$, $p = .240$, partial $\eta^2 = .043$). However, we observed a significant interaction between odor and concentration ($F[12,384] = 2.355$, $p = .006$, partial $\eta^2 = .069$). *Post-hoc* comparisons revealed that stimulating ratings at C5 concentration for lemon were higher than strawberry judgments at similar concentration (M = 7.276, SD = 1.945, M = 5.582, SD = 2.846, respectively, $p = .038$).

Planned comparisons were ran to compare judgments across odors through concentrations since according to the bidimensional model of emotions coffee and lemon (stimulating odors) were expected to be more stimulating and less relaxing than strawberry and lavender (relaxing odors) whatever the concentration. All concentrations revealed that lemon was significantly more stimulating than strawberry and lavender respectively $F(1,32) = 19.805$, $p < .001$, 95% CI [-9.88, -3.67] and $F(1,32) = 16.959$, $p < .001$, 95% CI [-10.07, -

3.40], but not than coffee (which probably accounts for the absence of main effect of odor on stimulating judgments).

3.2.2. Relaxing scale analysis

A repeated measure two-way ANOVA was conducted on relaxing ratings with odor (coffee, lemon, lavender, strawberry) and concentration (C1-C5) as within-factors. The analysis revealed a significant effect of concentration, $F(4, 128) = 9.457$, $p < .001$, partial $\eta^2 = .228$, indicating that the more concentrated an odorant is, the more relaxing the odor is perceived. There was also a main effect of odor, $F(3, 96) = 14.322$, $p < .001$, partial $\eta^2 = .309$, showing that relaxing ratings were significantly different across odors. These two main effects were further qualified by a significant interaction between odor and concentration, $F(12, 384) = 2.089$, $p = .017$, partial $\eta^2 = .061$, showing that lavender and strawberry were rated as increasingly relaxing for higher concentrations, which was not the case for coffee and lemon. *Post-hoc* comparisons revealed significant differences between low and medium-high concentrations for strawberry (between C2 and C4, $p = .016$) and lavender (C1 was significantly lower than C3, $p = .001$, C4 $p < .001$, and C5, $p = .034$). By contrast, variations of concentrations had no influence on the relaxing ratings for coffee and lemon.

Furthermore, planned comparisons revealed, as expected, that strawberry and lavender were significantly more relaxing than coffee ($F[1, 32] = 9.288$, $p = .004$, 95% CI [1.84, 9.24], and $F[1, 32] = 6.412$, $p = .016$, 95% CI [1.10, 10.19]). Moreover, the low values of the mean ratings for coffee on the relaxing scale (between 2.1 and 2.7) suggested that this odor was never considered relaxing. In this line, lemon differed from coffee with significant differences between these two odors (C3, $p = .002$, C4, $p = .012$, C5, $p = .049$) and higher means for lemon at medium-high concentrations C3 ($M = 4.855$, $SD = 2.888$), C4 ($M = 4.512$, $SD = 2.588$,) and C5 ($M = 3.936$, $SD = 2.844$). Interestingly, pairwise comparisons showed no significant difference between lemon and strawberry, nor between lemon and lavender at any concentration (all *p*s >.05).

3.3. Analysis of stimulating and relaxing judgments relationship as a function of odorant concentration

In order to investigate the relationship between relaxing and stimulating judgments planned comparisons and Spearman's correlation analyses were performed. According to the bidimensional model, an opposite relationship between relaxing and stimulating judgments for each odor was expected. Planned comparisons revealed that with increasing concentration, the relaxing judgments significantly evolved in a different way from the stimulating judgments for coffee ($F(1,32) = 52.336$, $p < .001$, 95% CI [-15.74,-8.83]) and lemon ($F(1,32) = 33.165$, $p < .001$, 95% CI [-15.99,-7.63]) but not for strawberry and lavender ($p > .05$). Pairwise comparisons showed significant differences between the two scales for coffee for C3 ($p < .001$), C4 ($p < .001$) and C5 ($p < .001$) and only for C4 ($p = .027$) and C5 ($p < .001$) for lemon. This means that coffee and lemon were perceived as significantly more stimulating than relaxing only for medium-high concentrations.

Spearman's correlation coefficients were calculated for each odorant concentration. Significant positive correlations ($p < .05$) were observed between relaxing and stimulating ratings for coffee at C2 ($r[31] = .384$), C3 ($r[31] = .402$) and C4 ($r[31] = .346$), for lemon at C1 ($r[31] = .419$), C2 ($r[31] = .467$), for strawberry at C1 ($r[31] = .730$), C2 ($r[31] = .492$) and for lavender at C1 ($r[31] = .661$), C2 ($r[31] = .599$).

T-test analyses with zero as a reference constant value were conducted for each odor on stimulating minus relaxing ratings differences. Mean values and *p*-values are presented in Table 3 for each concentration. A positive difference indicates that the odor was perceived significantly more stimulating than relaxing, a negative difference means the opposite. These analyses showed a stimulating dominance for coffee, becoming clearer as concentration increased from C2 to C5 (C1 was judged as equally relaxing and stimulating). Unexpectedly, lemon was judged significantly more relaxing than stimulating at the lowest concentration, as much relaxing as stimulating for C2 and C3 and shifted to clear stimulating dominance at the highest concentrations (i.e., C4 and C5). Strawberry and lavender were judged more relaxing than stimulating for lower concentrations (from C1 to C2 and from C1 to C3, respectively), then were judged as much relaxing as stimulating.

3.4. Analysis of profiles on relaxing and stimulating judgments as a function of odorant concentration

An analysis of individual rating profiles was conducted in order to examine if the bipolar profile predicted by the arousal dimension of the bidimensional model (i.e., when stimulating judgments increase, relaxing ones decrease) could be found at the individual level. For coffee, strawberry and lavender, this profile was displayed in only few participants (respectively N = 5, N = 6 and N = 5) whereas the largest group of participants followed the profile equivalent to the means (as shown in Figure 1, see supplementary material for details). Interestingly, for lemon only three participants followed the mean profile whereas most individual response patterns were distributed across 3 distinct profiles (see Figure 2): 1) both relaxing and stimulating ratings increasing through concentrations profile (profile 1, N = 11), 2) relaxing and stimulating ratings crossed-shaped through concentrations and can be considered as a “bipolar profile” (profile 2, N = 7), and 3) n-shaped relaxing ratings and rising stimulating ratings as a function of odorant concentration (profile 3, N = 7).

3.5. Analysis of pleasantness and familiarity judgments as a function of odorant concentration

Mean ratings of pleasantness and familiarity qualities are shown in Figure 3 for all odors as a function of concentration. A repeated measure two-way ANOVA on pleasantness and familiarity judgments was conducted with odor (coffee, lemon, lavender, strawberry) and concentration (C1-C5) as within-factors. The analysis of pleasantness judgments showed a main effect of odorant concentration, $F(4,128) = 23.618$, $p < .001$, partial $\eta^2 = .425$, and a main effect of odor $F(3,96) = 4.409$, $p = .006$, partial $\eta^2 = .121$. Pleasantness judgments increased with concentration for all odors. We observed a significant interaction between the odor and concentration, $F(12,384) = 2.471$, $p = .004$, partial $\eta^2 = .072$. In particular, pairwise comparisons showed lower pleasantness ratings for coffee compared to lemon judgments for similar levels of concentration at C3 ($p = .030$), C4 ($p = .002$) and C5 ($p < .001$). Coffee was also significantly less pleasant than strawberry for C5 concentration ($p = .001$).

The analysis carried out on familiarity judgments revealed a main effect of odorant concentration, $F(4, 128) = 71.577$, $p < .001$, partial $\eta^2 = .691$, no effect of odor, $F(3, 96) = 0.198$, $p = .897$, partial $\eta^2 = .006$, and no significant interaction between these factors, $F(12, 384) = 1.229$, $p = .261$, partial $\eta^2 = .037$. This showed that familiarity significantly increased with odorant concentration whatever the odor.

4. Discussion

The goal of the present study was to examine the relation between the concentration of an odorant and its perceived activation properties (relaxing and stimulating). In line with previous studies (Bensafi et al., 2002; Jin et al., 2018; Kikuchi et al., 1992), we observed a positive relationship between concentration, intensity and stimulating judgments for each odor indicating that whatever the odor, the more concentrated an odorant stimulus, the more intense and the more stimulating it was perceived. These observations expand earlier reports of a monotonic relationship between intensity and the stimulating properties of an odor, hence the commonly use of the former for a proxy of the latter (Anderson et al., 2003; Lewis et al., 2007; Winston et al., 2005).

Interestingly, however, relaxing judgements did not follow an inverse pattern with regards to stimulating judgements, as would have been expected within a bidimensional model. Instead, we found that for odors *a priori* considered "relaxing" (i.e., strawberry and lavender), relaxing judgments also increased with increasing stimulus concentration. At the highest concentrations, these odors were even perceived as much relaxing as stimulating. In other words, there were positive, not opposite, relations between relaxing and stimulating scales for considered relaxing odors (i.e., strawberry and lavender). These somewhat paradoxical results are however consistent with frameworks considering relaxing and stimulating properties as two independent dimensions (Chrea et al., 2009; Ferdenzi et al., 2011; Porcherot et al., 2010). Such a positive relationship between relaxing and stimulating scales are hard to reconcile with theories considering the activation properties of odors as one unified bipolar dimension opposing relaxing to stimulating labels (Feldman Barrett & Russell, 1998; Russell, 1980; Russell et al., 1989). Furthermore, relaxing judgments for odors commonly considered as "stimulating" (i.e., coffee and lemon) were not significantly influenced by the variations of concentration. Indeed, there were no negative correlations between relaxing and stimulating scales for these odors. Taken together, the current results suggest that relaxing and stimulating judgments should benefit from being considered as two distinct concepts rather than as extremes of a single dimension. Accordingly, these findings emphasize the need to use two independent unipolar scales in self-reports questionnaires when one wants to measure the relaxing and stimulating properties of odors. Further researches could for example investigate whether our results could be extended to other sensory modalities, especially with food-related emotions since the bidimensional theoretical framework still remains predominant and valence still being the most investigated dimension (den Uijl, Jager, Zandstra, de Graaf, & Kremer, 2016; Jaeger et al., 2018; Kaneko et al., 2018, 2019; Toet et al., 2018).

Our observations also disqualify the usual view, which considers intensity as a proxy for emotional arousal, at least for relaxing properties within the olfactory domain. In the current study, both strawberry and lavender were still perceived as relaxing at the strongest concentration, suggesting that the relationship between the relaxing properties of odors and stimulus concentration is neither direct nor systematic. Our findings thus suggest that to assimilate the odor intensity to its arousal properties could be misleading depending on the odor at hand, especially for relaxing judgments. It is worth mentioning that a similar pattern is not limited to olfactory-perceived emotions and can be found for other sensory modalities. In music for instance, intensity (i.e., loudness) is generally considered as a proxy for the arousal dimension. The arousing effect of loudness has recently been shown on explicit affective ratings (Karageorghis, Cheek, Simpson, & Bigliassi, 2018). More precisely, louder musical excerpts led participants to report higher scores on the Russell's Affect grid (Russell et al., 1989) compared to soft music or no-music control conditions. However, soft music was not associated with lower score on the Affect grid compared to no-music control condition, indicating that soft music was not necessarily considered as relaxing whereas loud music was strongly associated with stimulating properties. Altogether, these results mirror our findings showing that the intensity/arousal relation may be valid for stimulating judgments but is uncertain when it comes to relaxing properties.

We also found that the relaxing ratings of the lemon odor did not vary with concentration and were distributed around medium values, below the stimulating ratings for higher concentrations, but strikingly *above* them at the lower concentrations (see figure 1). The analysis of individual rating profiles showed that most participants answers corresponded to three different profiles: 1) an increase in both relaxing and stimulating ratings with concentration, 2) a cross-shaped ratings showing a shift from relaxing to stimulating perceived property with increasing concentration, 3) a n-shaped relaxing ratings and a rise of stimulating ratings (see Figure 2 for the three main profiles, and for more details, see Figure S6 of the supplementary material). Similar shifting patterns have been previously interpreted in terms of pungency of the odorant (Jin et al., 2018). However, in the present study, the very low ratings of perceived pungency (with a good interrater agreement) associated to our lemon odor at all odorant concentrations preclude a similar interpretation of our results. Future studies should closer examine the relationship between odorant pungency, odor perceived pungency and relaxing and stimulating properties to inform our understanding of olfactory perceived emotions.

Furthermore, our study points to the need to examine responses at the individual level since mean values might not fully represent the richness of olfactory-induced emotions. As mentioned by Köster (2002), averaging over subjects is the most used method in order to analyze the data whereas methods based on differences between subjects are still underrepresented. However, it has frequently been reported that great interindividual variability arises in response to a same olfactory stimulus, from earlier, sensory stages of stimulus processing, to the higher, more cognitive levels (Ferdenzi et al., 2016; Kaeppler & Mueller, 2013). Odors are both individually and collectively associated to specific emotions which are acquired and learnt according to individual personal experience and history, expertise or culture (Mohanty & Gottfried, 2013), and often at the very beginning of life (Mennella & Beauchamp, 1991, 1993, 1996; Mennella, Johnson, & Beauchamp, 1995; Schaal, Soussignan, & Marlier, 2002). These associations can vary also according to the perceiver context and motivation (Labbe, Ferrage, Rytz, Pace, & Martin, 2015). The potency of such odor-associative emotional learning has mainly been shown on hedonic responses (see R. Herz, 2002; R. Herz, 2005; R. Herz et al., 2004; Mohanty & Gottfried, 2013). For example, clove odor (eugenol), an odor which is typically associated to dental office, triggered a physiological pattern of fear for subjects who show fear for dental care but not for subjects who are not afraid of the dentist (Alaoui-Ismaïli, Robin, Rada, Dittmar, & Vernet-Maury, 1997). Moreover, in the same study, this odor was negatively judged only by fearful subjects, illustrating how very specific can individual experience of olfactory-elicited emotions be.

The representation of an odor is structured around several distinct parameters such as intensity, familiarity, the ability to name the odor (Distel et al., 1999) and its edibility (Ayabe-Kanamura et al., 1998). These parameters interact with affective properties. For instance, familiarity plays a key role in odor-induced emotions and more precisely in the valence-intensity relationship (Rouby et al., 2009), the more familiar an odor, the more pleasant (Knaapila et al., 2017) and the more intense it is perceived (Distel et al., 1999). Yet, these interactions have been much more extensively described in relation with hedonic valence (Mohanty & Gottfried, 2013) than with the relaxing and/or stimulating features. Here, our results are in line with an interdependent relationship between these variables. Moreover, the present study indicates that the modification of concentration impacts relaxing and stimulating properties in a distinct manner which partly depends on the participant. Mainly, the stimulating judgments increased along with intensity but the relaxing judgments patterns varied from one participant to another. At this earlier stage, explaining such a distinct impact of intensity on relaxing judgments across participants would be too speculative, especially because, it is very likely that several factors are involved. Nevertheless, it appears that individual differences in representations of an odor might find their origin in the aforementioned idiosyncratic odor-associative learning. Our results stress the need for further research to investigate the relationship between those variables, also considering interindividual variability especially in smell sensitivity which might impact perceived intensity and thus the whole relationship.

In this regard, it is plausible that many of the previously reported discrepancies in self-reports measures of relaxing and stimulating properties of odors stemmed also from differences in the odorant concentrations used (as already suggested by Jin et al., 2018). For instance, lemon can be perceived as relaxing at lower concentrations but as stimulating at stronger ones. Similarly, strawberry or lavender can be perceived both relaxing and stimulating at higher concentration. This could lead to large inter- and intra-individual variations, and consequently to inconsistent results across studies. This might be especially true since participants have generally been forced to use a single scale to report their judgments. Therefore, because activation properties of odors depend on intensity, future research should take into consideration the use of several concentrations for a given odorant, rather than to rely on the use of iso-intensity solutions of odors. Another source of discrepancies in the literature might come from the use, across studies, of very different products (i.e. compound mixtures of various chemical composition) which were supposed to have a same odor. For instance, it has been shown that different strawberry flavors lead to different emotional ratings (Porcherot et al., 2010).

In order to examine these different possible sources of discrepancies, it would seem good practices for future researches on olfactory induced emotion to use both explicit and implicit measures of arousal dimension manipulating for instance odorant concentration. A recent research (Lemercier-Talbot et al., 2019) has shown with an Implicit-Association Test that “relaxing” or “energizing” verbal labels can implicitly and automatically be associated with odors considered either as being relaxing (i.e., vanilla) or stimulating (i.e., mint). This fast association between emotional properties and olfactory stimuli point to profound ties between olfaction and emotions. According to our results, one might ask if this effect would be the same when using high intensities of lavender and strawberry, perceived as being relaxing and stimulating at the same time. The same question applies to odors such as lemon considered relatively relaxing at lower intensities and stimulating at higher ones; It would help to determine whether low intensities of lemon are implicitly associated to relaxing properties and high intensities to stimulating properties.

However, our study presents a few limitations that deserve to be discussed. It is known that odor quality can sometimes depend on concentration for a same odorant. For instance, alpha-ionone smells of violet at low concentration but of cedar wood at high concentration (Sengupta, Colbert, Kimmel, Dwyer, & Bargmann, 1993). As mentioned above, odor intensity is considered as one parameter influencing odors perception-based arrangements, listed by Kaeppler and Mueller (2013, see “odorant factor”). As described by these authors, the intensity of an odor can change its proper quality (Gross-Isseroff & Lancet, 1988; Laing, Legha, Jinks, & Hutchinson, 2003) as opposed to color perception where intensity does not change the basic hue quality. From this point of view, a limitation of our study is that we did not make sure that odors quality did not change with concentration, but this was a methodological choice since explicitly asking participants to describe and/or identify all the presented samples would have biased spontaneous answers via explicit suggestion effects for a same odorant and maybe between them (aside from the fact that it would have significantly impacted study length and probably participants implications in their task). Change in quality depending on odorant concentration poses interesting theoretical questions since concentration could activate distinct representations retrieved from episodic memory (potentially acquired from previous associative-learning). In olfaction, it is paramount to consider intensity as a dimension in affective response to odorants and not as a distinct dimension outside the affective space nor equivalent to a solitary quality dimension (Henion, 1971). As recommended also by Kaeppler and Mueller (2013), future researches should not only control for intensity of several odors by using equally intense stimuli from a pretest as is generally done, but they should also pretest several concentrations of a given odorant in order to check for misrepresentation of odors quality at every intensity level, since some odors may not have a single position within the olfactory space (Kaeppler & Mueller, 2013). But challenging methodological issues should first be solved, by using for example the above-mentioned IAT or indirect sorting or non-verbal matching tasks (preferably in experimental sessions temporally separated from explicit property ratings). Moreover, it might be important to use only one single odorant per experimental session.

A further limitation of the present study is that adaptation effects might have occurred, even careful precaution about this aspect was taken in the instructions given to the participant. We cannot exclude the possibility that a too short inter-stimulus interval may have reduced the stimulus perceived intensity or even make its perception impossible, and as a consequence, may bias the judgments. In any case, potential adaptation effects do not affect the main conclusions of our study with regard to the relaxing-stimulating relationship. Eventually, despite these inherent weaknesses, the relative role of the above-mentioned potential determinants and other influencing factors, such as adaptation kinetics, components of a complex odorant mixture and of their respective concentration, pungency properties, as well stimulus presentation mode (orthonasally vs. retronasally) open great perspectives for future research on relaxing and stimulating properties of odors.

5. Conclusions

In conclusion, our findings showed (1) a systematic link between concentration of chemical stimulus, odor perceived intensity and stimulating judgments for all odors, (2) a link between concentration of chemical stimulus, odor perceived intensity and relaxing judgments for *a priori* relaxing odors (i.e., strawberry and lavender) but not for *a priori* stimulating ones (e.g., coffee), and (3) a tendency to shift from relaxing at low concentration to stimulating at high concentrations for some odor (i.e., lemon). In the past, many researches on odors, flavors and aroma appreciation might have led to inconclusive and/or inapplicable results because the relaxing and stimulating properties of olfactory stimuli were not considered as two separate, affective dimensions, but rather as two opposite labels of a single one. As a first step, it was decided here to select four odors in order to have a better representation of relaxing and stimulating odors categories and five concentrations for a better sensitivity to odorant concentration manipulation. Overall, the current results stress the need to rely on separate unipolar scales when assessing the relaxing and stimulating properties of odors and encourage further studies, whether fundamental or applied, to integrate the use of different stimulus concentrations in experimental designs.

Acknowledgments

This work was supported by a PhD Scholarship from the French Ministery of Research awarded to A. B. The authors would like to thank Mériam Bacelard, Zoé Charton, Peter-Oluwaseyi Oyinseye and Laura Riffis for technical support.

References

Alaoui-Ismaïli, O., Robin, O., Rada, H., Dittmar, A., & Vernet-Maury, E. (1997). Basic emotions evoked by odorants: Comparison between autonomic responses and self-evaluation. *Physiology & Behavior, 62*(4), 713–720. https://doi.org/10.1016/S0031-9384(97)90016-0

Anderson, A. K., Christoff, K., Stappen, I., Panitz, D., Ghahremani, D. G., Glover, G., … Sobel, N. (2003). Dissociated neural representations of intensity and valence in human olfaction. *Nature Neuroscience*, *6*(2), 196–202. https://doi.org/10.1038/nn1001

Atsumi, T., & Tonosaki, K. (2007). Smelling lavender and rosemary increases free radical scavenging activity and decreases cortisol level in saliva. *Psychiatry Research*, *150*, 89–96. https://doi.org/10.1016/j.psychres.2005.12.012

Ayabe-Kanamura, S., Schicker, I., Laska, M., Hudson, R., Distel, H., Kobayakawa, T., & Saito, S. (1998). Differences in perception of everyday odors: A Japanese-German cross-cultural study. *Chemical Senses*, *23*(1), 31–38. https://doi.org/10.1093/chemse/23.1.31

Bensafi, M., Rouby, C., Farget, V., Bertrand, B., Vigouroux, M., & Holley, A. (2002). Autonomic nervous system responses to odours: The role of pleasantness and arousal. *Chemical Senses*, *27*(8), 703–709. https://doi.org/10.1093/chemse/27.8.703

Chastrette, M. (2002). Classification of odors and structure-odor relationships. In C. Rouby, B. Schaal, D. Dubois, R. Gervais, & A. Holley (Eds.), *Olfaction, Taste, and Cognition* (pp. 100–116). https://doi.org/10.1017/CBO9780511546389.012

Chebat, J.-C., & Michon, R. (2003). Impact of ambient odors on mall shoppers' emotions, cognition, and spending. *Journal of Business Research*, *56*(7), 529–539. https://doi.org/10.1016/s0148-2963(01)00247-8

Chrea, C., Grandjean, D., Delplanque, S., Cayeux, I., Le Calvé, B., Aymard, L., … Scherer, K. R. (2009). Mapping the semantic space for the subjective experience of emotional responses to odors. *Chemical Senses*, *34*(1), 49–62. https://doi.org/10.1093/chemse/bjn052

Dalton, P., Maute, C., Oshida, A., Hikichi, S., & Izumi, Y. (2008). The use of semantic differential scaling to define the multidimensional representation of odors. *Journal of Sensory Studies*, *23*(4), 485–497. https://doi.org/10.1111/j.1745-459X.2008.00167.x

Degel, J., & Köster, E. P. (1999). Odors : implicit memory and performance effects. *Chemical Senses*, *24*, 317–325.

Delplanque, S., Chrea, C., Grandjean, D., Ferdenzi, C., Cayeux, I., Porcherot, C., … Scherer, K. R. (2012). How to map the affective semantic space of scents. *Cognition and*

Emotion, *26*(5), 885–898. https://doi.org/10.1080/02699931.2011.628301

den Uijl, L. C., Jager, G., Zandstra, E. H., de Graaf, C., & Kremer, S. (2016). Self-reported food-evoked emotions of younger adults, older normosmic adults, and older hyposmic adults as measured using the PrEmo2 tool and the Affect Grid. *Food Quality and Preference*, *51*, 109–117. https://doi.org/10.1016/j.foodqual.2016.03.002

Diego, M. A., Jones, N. A., Field, T., Hernandez-Reif, M., Schanberg, S., Kuhn, C., … Galamaga, M. (1998). Aromatherapy positively affects mood, EEG patterns of alertness and math computations. *International Journal of Neuroscience*, *96*(3–4), 217–224. https://doi.org/10.3109/00207459808986469

Distel, H., Ayabe-Kanamura, S., Martinez-Gomez, M., Schiker, I., Kobayakawa, T., Saito, S., & Hudon, R. (1999). Perception of everyday odors—correlation between intensity familiarity and strength of hedonic judgment. *Chemical Senses*, *24*, 191–199.

Doty, R. L. (1975). An examination of relationships between the pleasantness, intensity, and concentration of 10 odorous stimuli. *Perception & Psychophysics*, *17*(5), 492–496. https://doi.org/10.3758/BF03203300

Doty, R. L., & Laing, D. G. (2015). Psychophysical measurement of human olfactory function. In R. L. Doty (Ed.), *Handbook of Olfaction and Gustation* (pp. 225–260). https://doi.org/10.1002/9781118971758.ch11

Feldman Barrett, L., & Russell, J. A. (1998). Independence and bipolarity in the structure of current affect. *Journal of Personality and Social Psychology*, *74*(4), 967–984. https://doi.org/10.1037/0022-3514.74.4.967

Ferdenzi, C., Joussain, P., Digard, B., Luneau, L., Djordjevic, J., & Bensafi, M. (2016). Individual differences in verbal and non-verbal affective responses to smells: Influence of odor label across cultures. *Chemical Senses*, *42*, 37–46. https://doi.org/10.1093/chemse/bjw098

Ferdenzi, C., Schirmer, A., Roberts, S. C., Delplanque, S., Porcherot, C., Cayeux, I., … Grandjean, D. (2011). Affective dimensions of odor perception: A comparison between Swiss, British, and Singaporean populations. *Emotion*, *11*(5), 1168–1181. https://doi.org/10.1037/a0022853

Ghiasi, A., Bagheri, L., & Haseli, A. (2019). A systematic review on the anxiolytic effect of aromatherapy during the first stage of labor. *Journal of Caring Sciences*, *8*(1), 51–60. https://doi.org/10.15171/jcs.2019.008

Gross-Isseroff, R., & Lancet, D. (1988). Concentration-dependent changes of perceived odor quality. *Chemical Senses*, *13*(2), 191–204.

Guéguen, N., & Petr, C. (2006). Odors and consumer behavior in a restaurant. *International Journal of Hospitality Management*, *25*(2), 335–339. https://doi.org/10.1016/j.ijhm.2005.04.007

He, W., de Wijk, R. A., de Graaf, C., & Boesveldt, S. (2016). Implicit and explicit measurements of affective responses to food odors. *Chemical Senses*, *41*(8), 661–668. https://doi.org/10.1093/chemse/bjw068

Henion, K. E. (1971). Odor pleasantness and intensity: A single dimension? *Journal of Experimental Psychology*, *90*(2), 275–279. https://doi.org/10.1037/h0031549

Herz, R. S. (2002). Influences of odors on mood and affective cognition. In C. Rouby, B. Schaal, D. Dubois, R. Gervais, & A. Holley (Eds.), *Olfaction, Taste and Cognition* (pp. 160–177). Cambridge: Cambridge Publications.

Herz, R. S. (2005). Odor-associative learning and emotion: Effects on perception and behavior. *Chemical Senses*, *30*, 250–251. https://doi.org/10.1093/chemse/bjh209

Herz, R. S. (2009). Aromatherapy facts and fictions: A scientific analysis of olfactory effects on mood, physiology and behavior. *International Journal of Neuroscience*, *119*(2), 263–290. https://doi.org/10.1080/00207450802333953

Herz, R. S., Schankler, C., & Beland, S. (2004). Olfaction, emotion and associative learning: Effects on motivated behavior. *Motivation and Emotion*, *28*(4), 363–383. https://doi.org/10.1007/s11031-004-2389-x

Herz, R. S., & von Clef, J. (2001). The influence of verbal labeling on the perception of odors: Evidence for olfactory illusions? *Perception*, *30*(3), 381–391. https://doi.org/10.1068/p3179

Heuberger, E., Hongratanaworakit, T., Böhm, C., Weber, R., & Buchbauer, G. (2001). Effects of chiral fragrances on human autonomic nervous system parameters and self-evaluation. *Chemical Senses*, *26*(3), 281–292. https://doi.org/10.1093/chemse/26.3.281

Hongratanaworakit, T. (2004). Physiological effects in aromatherapy. *Songklanakarin Journal of Science and Technology*, *26*(1), 117–125.

Hudson, R. (2000). Odor and odorant: A terminological clarification. *Chemical Senses*, *25*(693).

Iannilli, E., Sorokowska, A., Zhigang, Z., Hähner, A., Warr, J., & Hummel, T. (2015). Source localization of event-related brain activity elicited by food and nonfood odors. *Neuroscience*, *289*, 99–105. https://doi.org/10.1016/j.neuroscience.2014.12.044

Jaeger, S. R., Spinelli, S., Ares, G., & Monteleone, E. (2018). Linking product-elicited emotional associations and sensory perceptions through a circumplex model based on valence and arousal: Five consumer studies. *Food Research International*, *109*, 626–640.

https://doi.org/10.1016/j.foodres.2018.04.063

Jin, L., Haviland-jones, J., Simon, J. E., & Tepper, B. J. (2018). Influence of aroma intensity and nasal pungency on the ‘ mood signature ’ of common aroma compounds in a mixed ethnic population. *Food Quality and Preference*, *65*, 164–174. https://doi.org/10.1016/j.foodqual.2017.10.017

Jönsson, F. U., Olsson, H., & Olsson, M. J. (2005). Odor emotionality affects the confidence in odor naming. *Chemical Senses*, *30*(1), 29–35. https://doi.org/10.1093/chemse/bjh254

Kaeppler, K., & Mueller, F. (2013). Odor classification : A Review of factors influencing perception-based odor arrangements. *Chemical Senses*, *38*(3), 189–209. https://doi.org/10.1093/chemse/bjs141

Kaneko, D., Toet, A., Brouwer, A.-M., Kallen, V., & van Erp, J. B. F. (2018). Methods for evaluating emotions evoked by food experiences: A literature review. *Frontiers in Psychology*, *9*(911). https://doi.org/10.3389/fpsyg.2018.00911

Kaneko, D., Toet, A., Ushiama, S., Brouwer, A. M., Kallen, V., & van Erp, J. B. F. (2019). EmojiGrid: A 2D pictorial scale for cross-cultural emotion assessment of negatively and positively valenced food. *Food Research International*, *115*, 541–551. https://doi.org/10.1016/j.foodres.2018.09.049

Karageorghis, C. I., Cheek, P., Simpson, S. D., & Bigliassi, M. (2018). Interactive effects of music tempi and intensities on grip strength and subjective affect. *Scandinavian Journal of Medicine and Science in Sports*, *28*(3), 1166–1175. https://doi.org/10.1111/sms.12979

Kiecolt-Glaser, J. K., Graham, J. E., Malarkey, W. B., Porter, K., Lemeshow, S., & Glaser, R. (2008). Olfactory influences on mood and autonomic, endocrine, and immune function. *Psychoneuroendocrinology*, *33*(3), 328–339.

https://doi.org/10.1016/j.psyneuen.2007.11.015

Kikuchi, A., Yamaguchi, H., Tanida, M., Abe, T., & Uenoyama, S. (1992). Effects of odors on cardiac response patterns and subjective states in a reaction time task. *Tohoku Psychologica Folia*, *52*, 74–82.

Knaapila, A., Laaksonen, O., Virtanen, M., Yang, B., Lagström, H., & Sandell, M. (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

Komiya, M., Takeuchi, T., & Harada, E. (2006). Lemon oil vapor causes an anti-stress effect via modulating the 5-HT and DA activities in mice. *Behavioural Brain Research*, *172*(2), 240–249. https://doi.org/10.1016/j.bbr.2006.05.006

Köster, E. P. (2002). The specific characteristics of the sense of smell. In C. Rouby, B. Schaal, D. Dubois, R. Gervais, & A. Holley (Eds.), *Olfaction, Taste and Cognition* (pp. 27–44). United Kingdom: Cambridge Publications.

Köster, E. P., & Mojet, J. (2015). From mood to food and from food to mood: A psychological perspective on the measurement of food-related emotions in consumer research. *Food Research International*, *76,* 180–191. https://doi.org/10.1016/j.foodres.2015.04.006

Labbe, D., Ferrage, A., Rytz, A., Pace, J., & Martin, N. (2015). Pleasantness, emotions and perceptions induced by coffee beverage experience depend on the consumption motivation (hedonic or utilitarian). *Food Quality and Preference*, *44*, 56–61. https://doi.org/10.1016/j.foodqual.2015.03.017

Laing, D. G., Legha, P. K., Jinks, A. L., & Hutchinson, I. (2003). Relationship between molecular structure, concentration and odor qualities of oxygenated aliphatic molecules. *Chemical Senses*, *28*(1), 57–69. https://doi.org/10.1093/chemse/28.1.57

Lehrner, J., Eckersberger, C., Walla, P., Pötsch, G., & Deecke, L. (2000). Ambient odor of orange in a dental office reduces anxiety and improves mood in female patients. *Physiology & Behavior*, *71*(1–2), 83–86. https://doi.org/10.1016/S0031-9384(00)00308-5

Lehrner, J., Marwinski, G., Lehr, S., Johren, P., & Deecke, L. (2005). Ambient odors of orange and lavender reduce anxiety and improve mood in a dental office. *Physiology & Behavior*, *86*(1–2), 92–95. https://doi.org/10.1016/j.physbeh.2005.06.031

Lemercier-Talbot, A., Coppin, G., Cereghetti, D., Porcherot, C., Cayeux, I., & Delplanque, S. (2019). Measuring automatic associations between relaxing/energizing feelings and odors. *Food Quality and Preference*, *77*, 21–31. https://doi.org/10.1016/j.foodqual.2019.04.010

Lewis, P. A., Critchley, H. D., Rotshtein, P., & Dolan, R. J. (2007). Neural correlates of processing valence and arousal in affective words. *Cerebral Cortex*, *17*(3), 742–748. https://doi.org/10.1093/cercor/bhk024

Manley, C. H. (1993). Psychophysiological effect of odor. *Critical Reviews in Food Science and Nutrition*, *33*(1), 57–62. https://doi.org/10.1080/10408399309527612

Mennella, J. A., & Beauchamp, G. K. (1991). The transfer of alcohol to human milk: Effects on flavor and infants and the infant’s behavior. *New England Journal of Medicine*, *325*(14), 981–985. https://doi.org/10.1056/NEJM199309303291401

Mennella, J. A., & Beauchamp, G. K. (1993). The effects of repeated exposure to garlic-flavored milk on the nursling’s behavior. *Pediatric Research*, *34*(6), 805–808.

https://doi.org/10.1203/00006450-199312000-00022

Mennella, J. A., & Beauchamp, G. K. (1996). The human infants' response to vanilla flavors in mother's milk and formula. *Infant Behavior and Development*, *19*(1), 13–19. https://doi.org/10.1016/S0163-6383(96)90040-5

Mennella, J. A., Johnson, A., & Beauchamp, G. K. (1995). Garlic ingestion by pregnant women alters the odor of amniotic fluid. *Chemical Senses*, *20*(2), 207–209. https://doi.org/10.1093/chemse/20.2.207

Mohanty, A., & Gottfried, J. A. (2013). Examining emotion perception and elicitation via olfaction. In J. Armony & P. Vuilleumier (Eds.), *The Cambridge Handbook of Human Affective Neuroscience* (pp. 241–264). https://doi.org/10.1017/CBO9780511843716.014

Moskowitz, H. R., Dravnieks, A., & Klarman, L. A. (1976). Odor intensity and pleasantness for a diverse set of odorants. *Perception & Psychophysics, 19*(2), 122–128.

Moss, M., Hewitt, S., Moss, L., & Wesnes, K. (2008). Modulation of cognitive performance and mood by aromas of peppermint and ylang-ylang. *International Journal of Neuroscience, 118*(1), 59–77. https://doi.org/10.1080/00207450601042094

Motomura, N., Sakurai, A., & Yotsuya, Y. (2001). Reduction of mental stress with lavender odorant. *Perceptual and Motor Skills, 93*(3), 713–718. https://doi.org/10.2466/pms.2001.93.3.713

Mower, G. D., Mair, R. G., & Engen, T. (1977). Influence of internal factors on the perceived intensity and pleasantness of gustatory and olfactory stimuli. In M. R. Kare & O. Maller (Eds.), *The chemical senses and nutrition* (pp. 104–118). New York: Academic Press.

Piqueras-Fiszman, B., & Jaeger, S. R. (2014). Emotion responses under evoked consumption contexts: A focus on the consumers' frequency of product consumption and the stability of responses. *Food Quality and Preference*, *35*, 24–31. https://doi.org/10.1016/j.foodqual.2014.01.007

Porcherot, C., Delplanque, S., Raviot-Derrien, S., Calvé, B. Le, Chrea, C., Gaudreau, N., & Cayeux, I. (2010). How do you feel when you smell this? Optimization of a verbal measurement of odor-elicited emotions. *Food Quality and Preference*, *21*(8), 938–947. https://doi.org/10.1016/j.foodqual.2010.03.012

Pössel, P., Ahrens, S., & Hautzinger, M. (2005). Influence of cosmetics on emotional, autonomous, endocrinological, and immune reactions. *International Journal of Cosmetic Science*, *27*, 343–349. https://doi.org/10.1111/j.1467-2494.2005.00295.x

Rouby, C., Pouliot, S., & Bensafi, M. (2009). Odor hedonics and their modulators. *Food Quality and Preference*, *20*(8), 545–549. https://doi.org/10.1016/j.foodqual.2009.05.004

Royet, J.-P., Plailly, J., Delon-Martin, C., Kareken, D. A., & Segebarth, C. (2003). fMRI of emotional responses to odors: influence of hedonic valence and judgment, handedness, and gender. *NeuroImage*, *20*(2), 713–728. https://doi.org/10.1016/S1053-8119(03)00388-4

Russell, J. A. (1980). A circumplex model of affect. *Journal of Personality and Social Psychology*, *39*(6), 1161–1178. https://doi.org/10.1037/h0077714

Russell, J. A., Weiss, A., & Mendelsohn, G. A. (1989). Affect Grid: A single-item scale of pleasure and arousal. *Journal of Personality and Social Psychology*, *57*(3), 493–502.

Sayorwan, W., Siripornpanich, V., Piriyapunyaporn, T., Hongratanaworakit, T., Kotchabhakdi, N., & Ruangrungsi, N. (2012). The effects of lavender oil inhalation on emotional states, autonomic nervous system, and brain electrical activity. *Journal of the Medical Association of Thailand*, *95*(4), 598–606.

Sayowan, W., Siripornpanich, V., Hongratanaworakit, T., Kotchabhakdi, N., & Ruangrungsi, N. (2013). The effects of jasmine oil inhalation on brain wave activies and emotions. *Journal of Health Research*, *27*(2).

Schaal, B., Soussignan, R., & Marlier, L. (2002). Olfactory cognition at the start of life: The perinatal shaping of selective odor responsiveness. In C. Rouby, B. Schaal, D. Dubois, R. Gervais, & A. Holley (Eds.), *Olfaction, Taste and Cognition* (pp. 421–440). https://doi.org/10.1093/brain/awg287

Schifferstein, H. N. J., & Tanudjaja, I. (2004). Visualising fragrances through colours: the mediating role of emotions. *Perception*, *33*(10), 1249–1266. https://doi.org/10.1068/p5132

Sellaro, R., van Dijk, W. W., Rossi Paccani, C., Hommel, B., & Colzato, L. S. (2015). A question of scent: lavender aroma promotes interpersonal trust. *Frontiers in Psychology*, *5*(1486), 1–5. https://doi.org/10.3389/fpsyg.2014.01486

Sengupta, P., Colbert, H. A., Kimmel, B. E., Dwyer, N., & Bargmann, C. I. (1993). The cellular and genetic basis of olfactory responses in caenorhabditis elegans. In *The Molecular Basis of Smell and Taste Transduction* (pp. 235–250).

Smeets, M. A. M., & Dijksterhuis, G. B. (2014). Smelly primes - when olfactory primes do or do not work. *Frontiers in Psychology*, *5*(96), 1–10. https://doi.org/10.3389/fpsyg.2014.00096

Sorokowska, A., Negoias, S., Härtwig, S., Gerber, J., Iannilli, E., Warr, J., & Hummel, T. (2016). Differences in the central-nervous processing of olfactory stimuli according to their hedonic and arousal characteristics. *Neuroscience*, *324*, 62–68. https://doi.org/10.1016/j.neuroscience.2016.03.008

Sowndhararajan, K., & Kim, S. (2016). Influence of fragrances on human psychophysiological activity: with special reference to human electroencephalographic response. *Scientia Pharmaceutica*, *84*(4), 724–751. https://doi.org/10.3390/scipharm84040724

Toet, A., Kaneko, D., Ushiama, S., Hoving, S., Kruijf, I. De, Brouwer, A. M., … van Erp, J. B. F. (2018). EmojiGrid: A 2D pictorial scale for the assessment of food elicited emotions. *Frontiers in Psychology*, *9*, 1–21. https://doi.org/10.3389/fpsyg.2018.02396

Velasco, C., Balboa, D., Marmolejo-Ramos, F., & Spence, C. (2014). Crossmodal effect of music and odor pleasantness on olfactory quality perception. *Frontiers in Psychology*, *5*(1352), 1–9. https://doi.org/10.3389/fpsyg.2014.01352

Warm, J. S., Dember, W. N., & Parasuramen, R. (1991). Effects of olfactory stimulation on performance and stress in a visual sustained attention task. *Journal of the Society of Cosmetic Chemists*, *210*, 199–210.

Warren, C. B., Munteanu, M. A., Schwartz, G. E., Benaim, C., Walter, H. G. J., Leight, R. S., … Trenkle, R. W. (1987). *Patent No. 4,671,959*. United States.

Warren, C., & Warrenburg, S. (1993). Mood benefits of fragrance. *Perfumer & Flavorist*, *18*.

Warrenburg, S. (2002). Measurement of emotion in olfactory research. In P. Given & D. Paredes (Eds.), *Chemistry of Taste* (Vol. 825, pp. 243–260). https://doi.org/10.1021/bk-2002-0825.ch019

Warrenburg, S. (2005). Effects of fragrance on emotions: moods and physiology. *Chemical Senses*, *30*(Suppl_1), i248–i249. https://doi.org/10.1093/chemse/bjh208

Winston, J. S., Gottfried, J. A., Kilner, J. M., & Dolan, R. J. (2005). Integrated neural representations of odor intensity and affective valence in human amygdala. *Journal of*

Neuroscience, *25*(39), 8903–8907. https://doi.org/10.1523/jneurosci.1569-05.2005

Yeshurun, Y., & Sobel, N. (2010). An odor is not worth a thousand words: from multidimensional odors to unidimensional odor objects. *Annual Review of Psychology*, *61*(1), 219–241. https://doi.org/10.1146/annurev.psych.60.110707.163639

Zarzo, M. (2008). Psychologic dimensions in the perception of everyday odors: Pleasantness and edibility. *Journal of Sensory Studies*, *23*(3), 354–376. https://doi.org/10.1111/j.1745-459X.2008.00160.x

Tables captions

Table 1. *Concentrations in %v/v Retained for Each Odorant According to Intensity Mean Ratings.*

Table 2. *Means and Standard Deviation of the Intensity Ratings on a Visual Analog Scale (VAS) for Each Odor at Each Concentration.*

Table 3. *Mean Values of Difference Between Stimulating and Relaxing Ratings and p-values from Test of Means Against Zero as Reference Constant Value.*

Figures captions

Figure 1. Mean Value of Relaxing and Stimulating Ratings on a Visual Analog Scale (VAS) for Each Odor at Each concentration. Error Bars indicate Standard Error of the Mean.

Figure 2. Main Individual Profiles of Relaxing and Stimulating Ratings on a Visual Analog Scale (VAS) for Lemon Odor.

Figure 3. Mean Value of Familiarity and Pleasantness Ratings on a Visual Analog Scale (VAS) for Each Odor at Each Concentration. Error Bars Indicate Standard Error of the Mean.

Tables

Table 1. *Concentrations in %v/v Retained for Each Odorant According to Intensity Mean Ratings.*

	COFFEE		LEMON		STRAWBERRY		LAVENDER	
	Concentration	Intensity ratings	Concentration	Intensity ratings	Concentration	Intensity ratings	Concentration	Intensity ratings
C1	$9.766\ 10^{-2}$	3.73	$1.953\ 10^{-1}$	3.36	$9.766\ 10^{-2}$	3.14	$9.766\ 10^{-2}$	3.59
C2	$3.906\ 10^{-1}$	4.09	$7.813\ 10^{-1}$	5.36	$1.953\ 10^{-1}$	4.64	$3.906\ 10^{-1}$	4.95
C3	1.563	6.04	1.563	5.95	$7.813\ 10^{-1}$	6.81	$7.813\ 10^{-1}$	5.73
C4	3.125	7.23	6.250	7.14	1.563	7.32	3.125	7.41
C5	12.500	8.45	25.000	8.18	6.250	8.95	12.500	8.64

Table 2. *Means and Standard Deviation of the Intensity Ratings on a Visual Analog Scale (VAS) for Each Odor at Each Concentration.*

	COFFEE	LEMON	STRAWBERRY	LAVENDER
C1	1.57±1.44	2.22±2.11	2.78±2.33	2.18±2.38
C2	4.16±2.19	3.74±2.46	3.54±2.52	4.26±3.03
C3	6.11±2.05	4.55±2.43	5.94±2.29	5.09±2.30
C4	7.02±1.64	6.98±1.99	7.52±1.51	6.99±1.82
C5	8.63±1.37	8.40±1.51	8.24±1.47	8.69±1.31

Table 3. *Mean Values of Difference Between Stimulating and Relaxing Ratings and p-values from Test of Means Against Zero as Reference Constant Value.*

	COFFE		LEMON		STRAWBERRY		LAVENDER	
Concentration	*Mean* (*SD*)	*p*-value	*Mean* (*SD*)	*p*-value	*Mean* (*SD*)	*p*-value	*Mean* (*SD*)	*p*-value
C1	-0.503 (2.817)	.313	-1.315 (2.798)	.011*	-0.894 (1.999)	.015*	-1.148 (2.144)	.004*
C2	1.197 (2.457)	.009*	-0.836 (3.027)	.122	-1.124 (2.527)	.016*	-1.391 (2.460)	.003*
C3	2.521 (2.882)	<.001*	-0.664 (3.556)	.291	-0.579 (3.236)	.312	-1.227 (3.103)	.029*
C4	3.127 (3.065)	<.001*	1.667 (3.531)	.011*	0.155 (3.584)	.806	-1.115 (4.099)	.128
C5	4.676 (3.164)	<.001*	3.339 (3.727)	<.001*	0.552 (4.036)	.438	0.764 (4.467)	.333

$^*p < .05$

Figures

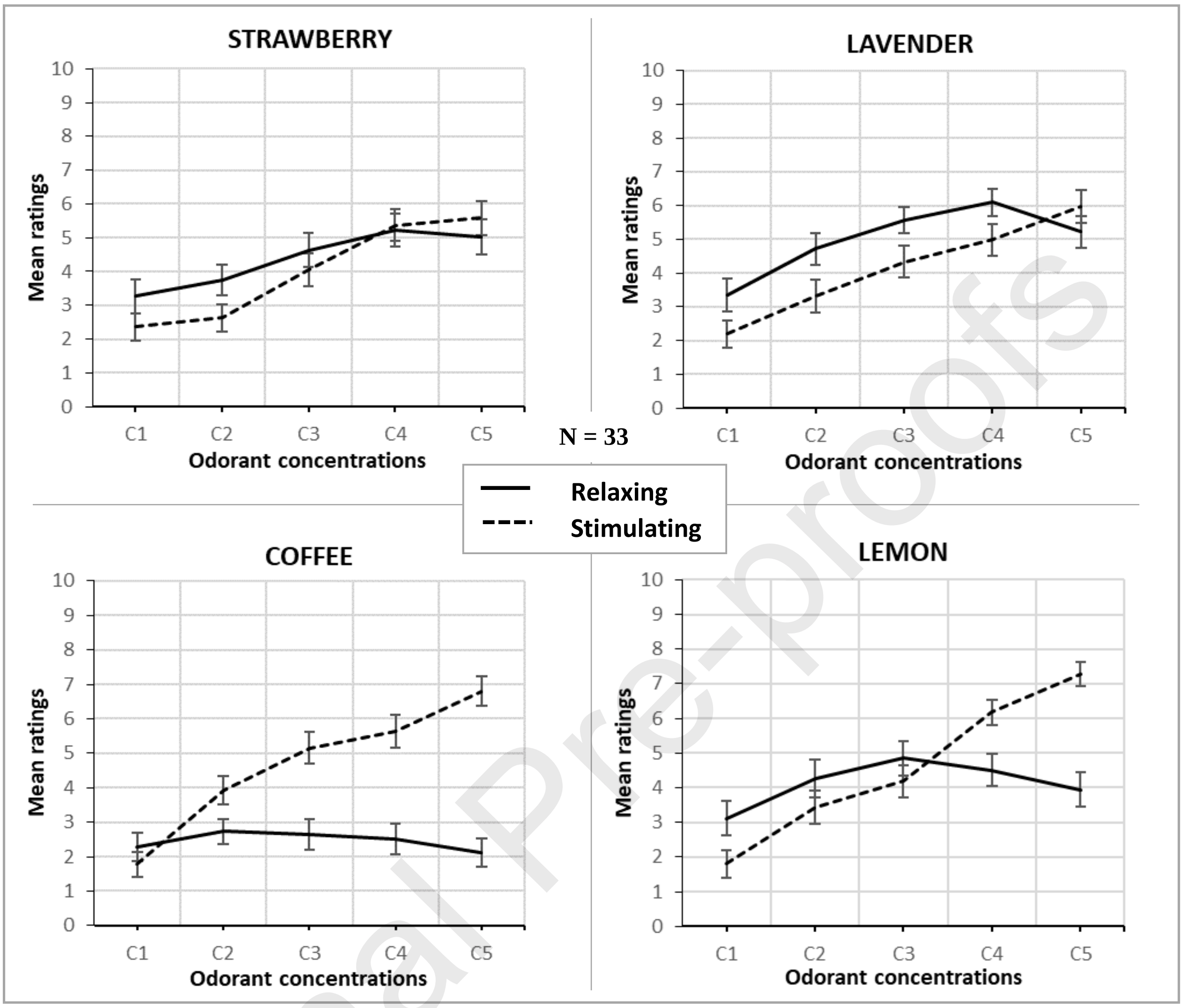


Figure 1. Mean Value of Relaxing and Stimulating Ratings on a Visual Analog Scale (VAS) for Each Odor at Each concentration. Error Bars indicate Standard Error of the Mean.

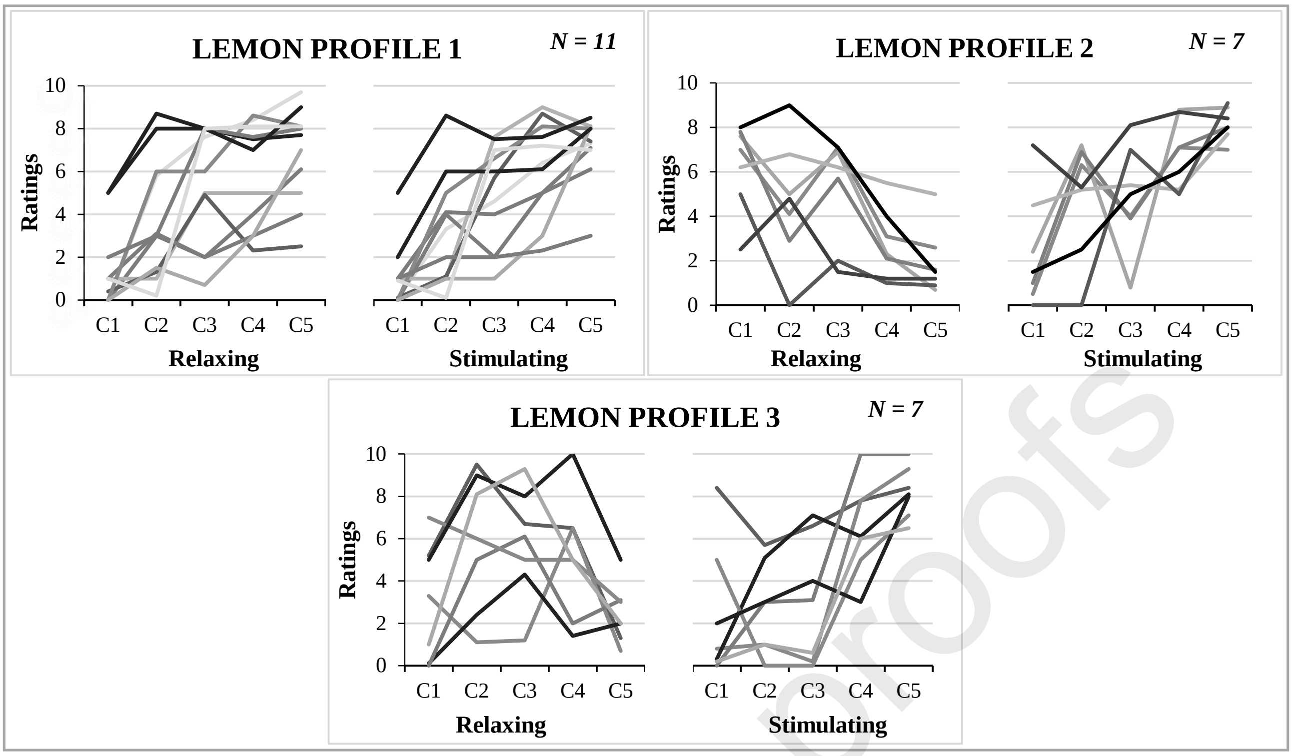


Figure 2. Main Individual Profiles of Relaxing and Stimulating Ratings on a Visual Analog Scale (VAS) for Lemon Odor.

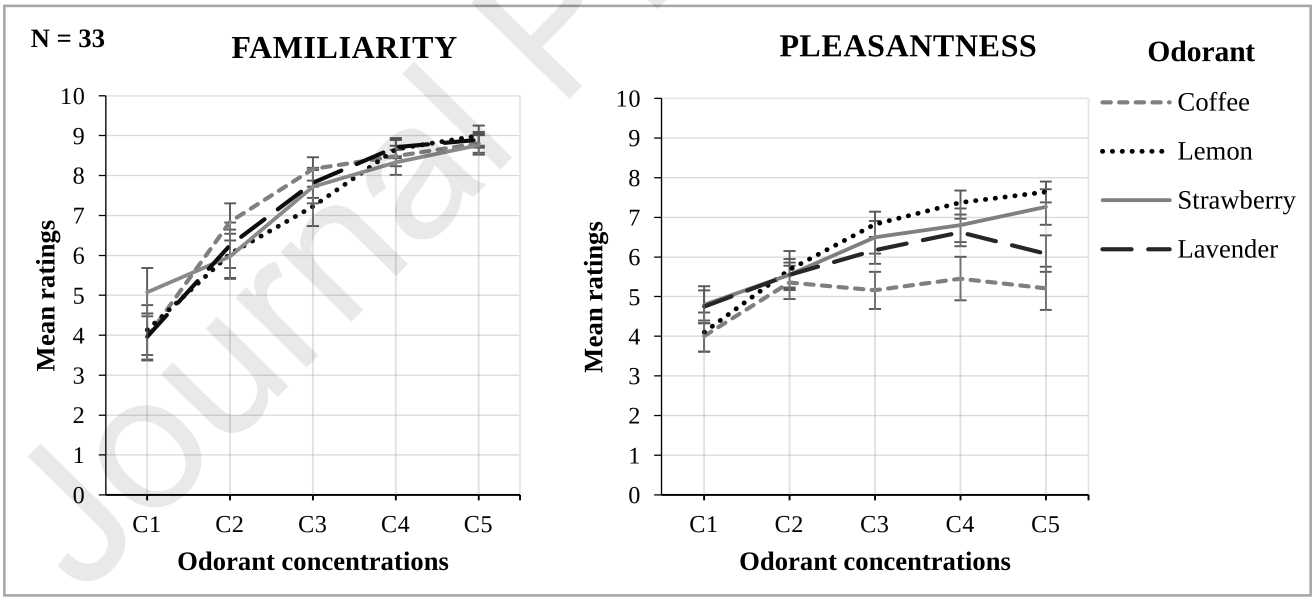


Figure 3. Mean Value of Familiarity and Pleasantness Ratings on a Visual Analog Scale (VAS) for Each Odor at Each Concentration. Error Bars Indicate Standard Error of the Mean.

Highlights

- All odors are judged more and more stimulating with increasing stimulus concentration.
- Some odors are also judged increasingly relaxing with stimulus concentration.
- Relaxing and stimulating labels should not be considered as two extremes of a single "arousal" dimension.

Authors statement

The manuscript is original, not previously published, and not under concurrent consideration elsewhere. The sample size was determined based on previous studies manipulating odorant concentration or examining perceived properties of odors. In addition, we included supplemental material to provide more details about pretests and individual data. Raw data will be made publicly available on OSF after the acceptance of the manuscript.

A. Baccarani, G. Brand, C. Dacremont, D. Valentin and R. Brochard