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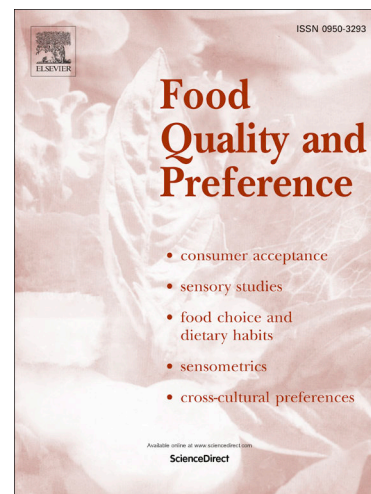
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1

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

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21 Abstract

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

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

42

43 1. Introduction

44 The use of scents to modulate mood is a common practice that seems to have always
45 accompanied humans. However, it was not until the last two decades that olfactory research
46 started to bring evidence supporting an emotional impact of scents, such as relaxing or
47 stimulating effects on physiology and behavior (Diego et al., 1998; Ghiasi, Bagheri, & Haseli,
48 2019; Lehrner, Marwinski, Lehr, Jöhren, & Deecke, 2005; Lemerrier-Talbot et al., 2019;
49 Motomura, Sakurai, & Yotsuya, 2001; Sayorwan et al., 2012; Sayowan, Siripornpanich,
50 Hongratanaworakit, Kotchabhakdi, & Ruangrunsi, 2013; for reviews see Herz, 2009 and
51 Hongratanaworakit, 2004). Perceived properties of odors and odor-elicited emotions are
52 commonly assessed with self-report questionnaires assessing valence and arousal dimensions
53 (in particular in food-related contexts, e.g. Jaeger, Spinelli, Ares, & Monteleone, 2018; for a
54 recent review see Kaneko, Toet, Brouwer, Kallen, & van Erp, 2018). Recent studies showed
55 that relaxing and stimulating properties are fundamental features of olfactory-induced
56 emotions (Chrea et al., 2009; Delplanque et al., 2012; Ferdenzi et al., 2011; Lemerrier-Talbot
57 et al., 2019; Porcherot et al., 2010). These relaxing and stimulating properties of olfactory
58 stimulus play an important role in daily activities. For instance, food aromas and flavors are
59 part of our daily sensory experiences, and are known to be relaxing and stimulating (Jaeger et
60 al., 2018; Kaneko et al., 2018; Köster & Mojet, 2015; Piqueras-Fiszman & Jaeger, 2014; Toet
61 et al., 2018).

62 *Discrepancies in olfactory relaxing and stimulating properties*

63 Conflicting findings regarding activation properties of odors have been reported in the
64 literature, with the very same odor having been described either relaxing or stimulating
65 depending on the study (Atsumi & Tonosaki, 2007; Jin, Haviland-jones, Simon, & Tepper,
66 2018; Kiecolt-Glaser et al., 2008; Kikuchi, Yamaguchi, Tanida, Abe, & Uenoyama, 1992;
67 Komiya, Takeuchi, & Harada, 2006; Lehrner, Eckersberger, Walla, Pötsch, & Deecke, 2000;

68 Manley, 1993; Moss, Hewitt, Moss, & Wesnes, 2008; Porcherot et al., 2010; Warren &
69 Warrenburg, 1993). For instance, the odor of lemon has been found stimulating in some
70 studies which used physiological measurements (Kiecolt-Glaser et al., 2008; Kikuchi et al.,
71 1992), whereas others highlighted a relaxing effect of this odor (e.g., Manley, 1993, see also
72 Komiya, Takeuchi, & Harada, 2006, for an anti-stress effect of lemon in behavioral tasks in
73 mice). A similar discrepancy has been reported for both rosemary and nutmeg, which have
74 been found to be relaxing based on physiological measurements of arousal (Atsumi &
75 Tonosaki, 2007; Warren, 1987; Warren & Warrenburg, 1993), but stimulating based on
76 performance in cognitive tasks (i.e., an increase in memory performance for rosemary, Moss
77 et al., 2008) or even failed to show any relaxing or stimulating effect (i.e., for nutmeg, Warm,
78 Dember, & Parasuramen, 1991; Warren & Warrenburg, 1993). Although these mixed
79 evidences might stem from distinct methodological approaches (e.g., behavioral,
80 physiological, etc.; see Herz, 2009; Sowndhararajan & Kim, 2016), discrepancies simply
81 occur in subjective judgments. For example, peppermint is judged as stimulating in some
82 studies (Moss et al., 2008; Warm et al., 1991) but scored low on an “activation scale” in
83 others (Dalton, Maute, Oshida, Hikichi, & Izumi, 2008; Sellaro, van Dijk, Rossi Paccani,
84 Hommel, & Colzato, 2015). The olfactory stimulus used might be at the root of such
85 inconsistencies across studies. For instance, it has been shown that different flavors of
86 strawberry can lead to distinct perceived emotional properties (Porcherot et al., 2010). These
87 authors examined the emotional ratings of six different strawberry-flavored products, i.e.,
88 fruity strawberry, floral strawberry, cooked strawberry, creamy strawberry, green strawberry
89 and wild strawberry solutions. Their analysis revealed a significant Product \times Emotional
90 Dimension interaction, with products being rated differentially depending on the emotions.
91 Higher scores were given to the “Disgusted – Irritated – Unpleasantly surprised” dimension

92 for the “green” and “floral” strawberry flavors than for the “fruity” and “cooked”
93 strawberry flavors.

94 Beyond the aforementioned methodological and measurement issues, discrepancies
95 may also emerge because activation properties of odors have been considered within different
96 theoretical frameworks (e.g., Herz, 2009; Kaeppler & Mueller, 2013; Sowndhararajan & Kim,
97 2016). The circumplex model of affect (Feldman Barrett & Russell, 1998; Russell, 1980), is
98 an influential model of emotion broadly used within the olfactory domain (Anderson et al.,
99 2003; Bensafi et al., 2002; Chebat & Michon, 2003; Herz, Schankler, & Beland, 2004;
100 Heuberger, Hongratanaworakit, Böhm, Weber, & Buchbauer, 2001; Jönsson, Olsson, &
101 Olsson, 2005; Pössel, Ahrens, & Hautzinger, 2005; Schifferstein & Tanudjaja, 2004;
102 Warrenburg, 2005). In this model, valence and arousal are thought of as two independent
103 dimensions of emotions. Valence reflects the pleasant-unpleasant properties of emotional
104 stimuli, whereas emotional arousal reflects activating-deactivating properties. In a nutshell,
105 this means that the more relaxing an odor the less stimulating it is. Although both dimensions
106 are essential parts of the model, valence was typically conceived as the key function in
107 olfaction, and for some authors was even seen as the “primary axis of odor perception” (He,
108 de Wijk, de Graaf, & Boesveldt, 2016; Knaapila et al., 2017; Yeshurun & Sobel, 2010).
109 Accordingly, valence certainly benefited of more interest from the research community than
110 the arousal dimension.

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

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

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

133 First of all, it is important to note that the olfactory stimulus is generally referred to as
134 the « odorant » whereas the percept is called the « odor » (Hudson, 2000; Smeets &
135 Dijksterhuis, 2014). In this view, concentration refers to the objective odorant’s quantity of
136 chemical compounds, whilst intensity refers to the perceived property of an odor. Considering
137 the large interindividual variability in smell sensitivity and detection thresholds (Chastrette,
138 2002; Doty & Laing, 2015), studies examining olfactory emotions are typically run at
139 perceived iso-intensity to allow for comparisons, thus with only one concentration per
140 odorant. However, the concentration of an odorant has been proven to bear a crucial influence
141 on the emotion elicited (Distel et al., 1999; Doty, 1975; Gross-isseroff & Lancet, 1988;

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

151 By contrast with valence, the interaction between concentration and the activation
152 properties might have been slightly overlooked. Previous studies have reported positive
153 correlations between odor intensity and arousal ratings (Bensafi et al., 2002; Chrea et al.,
154 2009), leading to the view that the perceived intensity could even be seen as a substitute for
155 the arousal dimension of olfactory emotions (e.g., Anderson et al., 2003; Lewis, Critchley,
156 Rotshtein, & Dolan, 2007; Winston, Gottfried, Kilner, & Dolan, 2005). However,
157 conceptualizing odor intensity as a proxy of emotional arousal properties of an odor might be
158 too simplistic considering that some odorants can be stimulating at very low concentrations,
159 and even at subliminal levels as showed by implicit measure (e.g., low level of lavender
160 essential oil enhances memory performance, Degel & Köster, 1999).

161 A recent study specifically investigated the relationship between the emotional
162 perceived properties of an odor and the corresponding odorant concentration on subjective
163 measures (Jin et al., 2018). Findings showed that the main emotion property (“mood signature
164 method”) of an odor could change from low to medium-high odorant concentration, and even
165 shift from “calm-relaxed” at low concentration to “exciting-energized” properties at mid-
166 range concentration. This shift could be related to the pungency of the odorant at higher

167 concentrations (Jin et al., 2018), and thus may be odorant-specific. These results are in line
168 with prior studies showing direct relationship between a potential “arousal dimension” and
169 odor perceived intensity. It is worth mentioning however that the use of forced-choice in the
170 “mood signature method” led the participants to choose between potentially important
171 emotional properties, thus meeting similar limitations as the bidimensional scales (assuming
172 that an odor can be either relaxing or stimulating). Although such a method is relevant to
173 identify dominant perceived emotion, it might be less suited to investigate the complexity and
174 richness of emotions elicited by odors.

175 The purpose of the present study was thus to investigate the role of odorant
176 concentration on the perceived relaxing and stimulating properties of odors (strawberry,
177 lavender, coffee, and lemon), on two independent scales, in order to test potentially distinct
178 effects of concentration. Previous studies assessing the role of concentration on stimulating
179 and relaxing judgments have typically contrasted few concentrations (e.g., two
180 concentrations, Jin et al., 2018; three concentrations, Kikuchi et al., 1992), thus preventing a
181 fine-grained examination of the effect of odorant concentration on olfactory-perceived
182 emotions. In the present study, we collected judgments for five levels of odorant
183 concentration, with equivalent perceived intensity across odors at each level. According to
184 bidimensional conceptions, we expect a negative relationship between stimulating and
185 relaxing properties. In other words, high relaxing judgments should be accompanied by low
186 stimulating judgments, and conversely. However, according to multidimensional conceptions,
187 relaxing and stimulating properties of an odor might be judged independently. Henceforth, we
188 expect either a positive relationship between relaxing and stimulating judgments or even no
189 relation at all. A second goal of the present study was to determine whether the relationship
190 between the activation properties and the odor intensity is straightforward as previously
191 shown by studies using a bidimensional model. If so, the activation properties of odors should

192 mirror the level of odorant concentrations, irrespective of their *a priori* relaxing or stimulating
193 property. For instance, odors previously identified either as “stimulating” (i.e., coffee and
194 lemon) or “relaxing” (i.e., strawberry and lavender) should nevertheless be found relaxing at
195 lower odorant concentrations and stimulating at higher ones. Furthermore, in the present
196 study, participants were presented with pleasant odors only, since valence interacts with
197 intensity and could be a potential confounding variable. In addition, unpleasant odors with
198 low level of arousal are quite rare since unpleasant odors are generally also arousing (Bensafi
199 et al., 2002; Royet, Plailly, Delon-Martin, Kareken, & Segebarth, 2003; Sorokowska et al.,
200 2016; Velasco, Balboa, Marmolejo-Ramos, & Spence, 2014). In addition, only aromas were
201 used here in order to study a homogenous set of food-related odors since potential distinct
202 mechanisms might underlie non-food-related stimuli (Iannilli et al., 2015; Zarzo, 2008). That
203 being said, and as commonly done in the field, pleasantness and familiarity judgments were
204 also collected to check for potential modulating effect of these factors.

205 **2. Method**

206 ***2.1. Pre-test: preselection of odorant concentrations***

207 We selected coffee and lemon as stimulating odors, and strawberry and lavender as
208 relaxing ones based on prior literature (Chrea et al., 2009; Guéguen & Petr, 2006; Lehrner et
209 al., 2005; Porcherot et al., 2010) and pre-screening on the basis of judgments among a
210 collection of 18 odors. Strawberry and lavender were considered to be the most relaxing
211 among the 18 odors presented at iso-intensity and lemon and coffee the most stimulating.
212 Then, the present pre-test was run in order to determine for each of the four preselected odors
213 the five concentrations to be used in the main experiment. During this pre-test, 24
214 concentrations for each odorant were prepared into 60 mL brown glass vials using a 2-fold
215 serial dilutions method protocol (considering 0.5 factor dilution, the first vial contained a
216 50.000% v/v solution and the last one, the most diluted, a 5.961 10⁻⁶% v/v solution). Coffee,

217 lemon, strawberry and lavender odorants were prepared from artificial aromas selected from
218 “*Le meilleur du chef*®” website: “Arôme café note Colombie, SELECTARÔME”, 58 mL;
219 “Arôme naturel citron, SELECTARÔME”, 58 mL; “Arôme fraise, SELECTARÔME”, 58
220 mL; “Arôme naturel lavande, SELECTARÔME”, 58 mL. Two different solvents were used to
221 obtain equivalent miscible solutions: strawberry and coffee were diluted in distilled water,
222 and lavender and lemon were diluted in mineral oil (SIGMA-Aldrich, France). Eventually, 2
223 mL of the final solution were placed in a 60 mL brown glass vial on a fine-fiber dark
224 absorbent (3x3 cm, 100% polypropylene fine fibers, 38 l/UV absorption, *DENSORB*,
225 “*Universal*” Light, DENIOS®) in order to mask the color of the odorants.

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

235 The next step was to select the final five odorant concentration levels for each odor.
236 Each olfactory stimulus of a given level had to be perceived as equally intense. Twenty-eight
237 participants (16 females) assessed the odor intensity of the 20 odorant concentrations
238 (presented in Table S1 in supplementary material) for each odor on a 11-point Likert scale
239 (from 0 = *not perceived at all* to 10 = *extremely intense*) in a 1-hour session. Olfactory stimuli
240 were prepared following the same procedure, the 20 concentrations of each odorant were

241 prepared into 60 mL brown glass vials following a factor-two dilution cascade (the first vial
242 contained a 50.000 %v/v solution and the most diluted, a $9.537 \cdot 10^{-5}$ %v/v solution, see Table
243 S1 of the supplementary material). Participants sat in a quiet and well-ventilated room. They
244 were given a reference point to anchor the highest intensity of the scale by initially presenting
245 the highest odorant concentration for each odor. Presentation of odors and concentrations
246 were both randomized. During this session, participants had no time constraint and could sniff
247 the stimulus as much as they needed before ratings. Nevertheless, in order to minimize
248 adaptation effects, participants were asked to wait at least a few seconds after their ratings,
249 before switching to another stimulus, and to smell their own clothes between each sample.
250 They could drink water as much as they needed but they were encouraged to drink after an
251 odor judged particularly intense. They took a short break (a few minutes) every 10 stimuli and
252 a longer break (at least 10 minutes) in the middle of the session.

253 In order to have each olfactory stimulus of a given concentration level perceived as
254 equally intense across odors, a linear regression analysis was performed on mean intensity
255 ratings for the 20 odorant concentrations of each odor (see Figure S1 and Figure S2 in
256 supplementary material). It allowed for identifying odorant concentrations leading to five
257 intensity levels evenly spread out on the intensity scale (see Table 1), i.e., 3.1 to 3.7 - 4.1 to
258 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
259 concentrations in volume/volume percentage retained for each olfactory stimulus for the main
260 experiment is provided in supplementary material (Figure S3).

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

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

269 **2.2. Main experiment**

270 *2.2.1. Participants*

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

275 *2.2.2. Procedure*

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

290 Emotion and Odor Scale (EOS) in relation with relaxing and energizing feelings (Chrea et al.,
291 2009) rather than with the positive additional labels of the Affect Grid (i.e., “excitement” and
292 “relaxation”; Russell, Weiss, & Mendelsohn, 1989) which are not specific of olfactory-
293 elicited emotions. A reference point for intensity judgment was given by presenting each of
294 four odorants at their maximal concentration. Participants had no time constraint and could
295 sniff the odorants as much as they needed before answering the questions. The time interval
296 between each concentration corresponded to the time required to complete the five scales. In
297 order to minimize adaptation effects, participants were asked to wait at least a few seconds
298 after their ratings before switching to the next stimulus, and to smell their own clothes
299 between each sample. They could drink as much water as they needed and were encouraged
300 to drink after a judged particularly intense odor and to wait a bit longer.

301 2.2.3. *Data analysis*

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

308 3. Results

309 3.1. *Analysis of intensity ratings as a function of odorant concentration*

310 To ensure that each intensity level was perceived as iso-intense for the four odors we
311 ran a repeated-measure two-way ANOVA on intensity ratings with odor (coffee, lemon,
312 lavender, strawberry) and concentration (C1-C5) as within-factors (the means and standard
313 deviations are presented in Table 2). As expected, the analysis yielded a main effect of

314 concentration on intensity ratings $F(12, 384) = 2.091, p = .017$, partial $\eta^2 = .061$, indicating
315 that perceived intensity increased with physical concentration for all odorants. Importantly for
316 our purpose, there was no significant effect of odor nor interaction (all $ps > .05$), further
317 indicating that each of the five levels of concentration were well matched in perceived
318 intensity across odors.

319 **3.2. Analysis of stimulating and relaxing ratings as a function of odorant concentration**

320 **3.2.1. Stimulating scale analysis**

321 A repeated-measure two-way ANOVA was conducted on stimulating judgments with
322 odor (coffee, lemon, lavender, strawberry) and concentration (C1-C5) as within-factors. This
323 analysis showed a main effect of concentration on ratings, $F(4,128) = 84.757, p < .001$,
324 partial $\eta^2 = .726$, indicating that stimulating judgments increased with concentration for all
325 odors (see Figure 1), even for the odors considered as relaxing (i.e., lavender and strawberry).
326 There was no main effect of odor on stimulating judgments ($F[3,96] = 1.425, p = .240$, partial
327 $\eta^2 = .043$). However, we observed a significant interaction between odor and concentration
328 ($F[12,384] = 2.355, p = .006$, partial $\eta^2 = .069$). *Post-hoc* comparisons revealed that
329 stimulating ratings at C5 concentration for lemon were higher than strawberry judgments at
330 similar concentration ($M = 7.276, SD = 1.945, M = 5.582, SD = 2.846$, respectively, $p =$
331 $.038$).

332 Planned comparisons were ran to compare judgments across odors through
333 concentrations since according to the bidimensional model of emotions coffee and lemon
334 (stimulating odors) were expected to be more stimulating and less relaxing than strawberry
335 and lavender (relaxing odors) whatever the concentration. All concentrations revealed that
336 lemon was significantly more stimulating than strawberry and lavender respectively $F(1,32) =$
337 $19.805, p < .001, 95\% CI [-9.88, -3.67]$ and $F(1,32) = 16.959, p < .001, 95\% CI [-10.07, -$

338 3.40], but not than coffee (which probably accounts for the absence of main effect of odor on
339 stimulating judgments).

340 3.2.2. *Relaxing scale analysis*

341 A repeated measure two-way ANOVA was conducted on relaxing ratings with odor
342 (coffee, lemon, lavender, strawberry) and concentration (C1-C5) as within-factors. The
343 analysis revealed a significant effect of concentration, $F(4, 128) = 9.457, p < .001$, partial $\eta^2 =$
344 $.228$, indicating that the more concentrated an odorant is, the more relaxing the odor is
345 perceived. There was also a main effect of odor, $F(3, 96) = 14.322, p < .001$, partial $\eta^2 = .309$,
346 showing that relaxing ratings were significantly different across odors. These two main effects
347 were further qualified by a significant interaction between odor and concentration, $F(12, 384)$
348 $= 2.089, p = .017$, partial $\eta^2 = .061$, showing that lavender and strawberry were rated as
349 increasingly relaxing for higher concentrations, which was not the case for coffee and lemon.
350 *Post-hoc* comparisons revealed significant differences between low and medium-high
351 concentrations for strawberry (between C2 and C4, $p = .016$) and lavender (C1 was
352 significantly lower than C3, $p = .001$, C4 $p < .001$, and C5, $p = .034$). By contrast, variations
353 of concentrations had no influence on the relaxing ratings for coffee and lemon.

354 Furthermore, planned comparisons revealed, as expected, that strawberry and lavender
355 were significantly more relaxing than coffee ($F[1, 32] = 9.288, p = .004$, 95% CI [1.84, 9.24],
356 and $F[1, 32] = 6.412, p = .016$, 95% CI [1.10, 10.19]). Moreover, the low values of the mean
357 ratings for coffee on the relaxing scale (between 2.1 and 2.7) suggested that this odor was
358 never considered relaxing. In this line, lemon differed from coffee with significant differences
359 between these two odors (C3, $p = .002$, C4, $p = .012$, C5, $p = .049$) and higher means for
360 lemon at medium-high concentrations C3 ($M = 4.855, SD = 2.888$), C4 ($M = 4.512, SD =$
361 2.588), and C5 ($M = 3.936, SD = 2.844$). Interestingly, pairwise comparisons showed no

362 significant difference between lemon and strawberry, nor between lemon and lavender at any
363 concentration (all p s $>.05$).

364 ***3.3. Analysis of stimulating and relaxing judgments relationship as a function of odorant*** 365 ***concentration***

366 In order to investigate the relationship between relaxing and stimulating judgments
367 planned comparisons and Spearman's correlation analyses were performed. According to the
368 bidimensional model, an opposite relationship between relaxing and stimulating judgments
369 for each odor was expected. Planned comparisons revealed that with increasing concentration,
370 the relaxing judgments significantly evolved in a different way from the stimulating
371 judgments for coffee ($F(1,32) = 52.336, p < .001, 95\% \text{ CI } [-15.74, -8.83]$) and lemon ($F(1,32)$
372 $= 33.165, p < .001, 95\% \text{ CI } [-15.99, -7.63]$) but not for strawberry and lavender ($p >.05$).
373 Pairwise comparisons showed significant differences between the two scales for coffee for C3
374 ($p < .001$), C4 ($p < .001$) and C5 ($p < .001$) and only for C4 ($p = .027$) and C5 ($p < .001$) for
375 lemon. This means that coffee and lemon were perceived as significantly more stimulating
376 than relaxing only for medium-high concentrations.

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

382 T-test analyses with zero as a reference constant value were conducted for each odor
383 on stimulating minus relaxing ratings differences. Mean values and p -values are presented in
384 Table 3 for each concentration. A positive difference indicates that the odor was perceived
385 significantly more stimulating than relaxing, a negative difference means the opposite. These

386 analyses showed a stimulating dominance for coffee, becoming clearer as concentration
387 increased from C2 to C5 (C1 was judged as equally relaxing and stimulating). Unexpectedly,
388 lemon was judged significantly more relaxing than stimulating at the lowest concentration, as
389 much relaxing as stimulating for C2 and C3 and shifted to clear stimulating dominance at the
390 highest concentrations (i.e., C4 and C5). Strawberry and lavender were judged more relaxing
391 than stimulating for lower concentrations (from C1 to C2 and from C1 to C3, respectively),
392 then were judged as much relaxing as stimulating.

393 ***3.4. Analysis of profiles on relaxing and stimulating judgments as a function of odorant*** 394 ***concentration***

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

407 ***3.5. Analysis of pleasantness and familiarity judgments as a function of odorant concentration***

408 Mean ratings of pleasantness and familiarity qualities are shown in Figure 3 for all
409 odors as a function of concentration. A repeated measure two-way ANOVA on pleasantness

410 and familiarity judgments was conducted with odor (coffee, lemon, lavender, strawberry) and
411 concentration (C1-C5) as within-factors. The analysis of pleasantness judgments showed a
412 main effect of odorant concentration, $F(4,128) = 23.618$, $p < .001$, partial $\eta^2 = .425$, and a
413 main effect of odor $F(3,96) = 4.409$, $p = .006$, partial $\eta^2 = .121$. Pleasantness judgments
414 increased with concentration for all odors. We observed a significant interaction between the
415 odor and concentration, $F(12,384) = 2.471$, $p = .004$, partial $\eta^2 = .072$. In particular, pairwise
416 comparisons showed lower pleasantness ratings for coffee compared to lemon judgments for
417 similar levels of concentration at C3 ($p = .030$), C4 ($p = .002$) and C5 ($p < .001$). Coffee was
418 also significantly less pleasant than strawberry for C5 concentration ($p = .001$).

419 The analysis carried out on familiarity judgments revealed a main effect of odorant
420 concentration, $F(4, 128) = 71.577$, $p < .001$, partial $\eta^2 = .691$, no effect of odor, $F(3, 96) =$
421 0.198 , $p = .897$, partial $\eta^2 = .006$, and no significant interaction between these factors, $F(12,$
422 $384) = 1.229$, $p = .261$, partial $\eta^2 = .037$. This showed that familiarity significantly increased
423 with odorant concentration whatever the odor.

424 **4. Discussion**

425 The goal of the present study was to examine the relation between the concentration of
426 an odorant and its perceived activation properties (relaxing and stimulating). In line with
427 previous studies (Bensafi et al., 2002; Jin et al., 2018; Kikuchi et al., 1992), we observed a
428 positive relationship between concentration, intensity and stimulating judgments for each odor
429 indicating that whatever the odor, the more concentrated an odorant stimulus, the more
430 intense and the more stimulating it was perceived. These observations expand earlier reports
431 of a monotonic relationship between intensity and the stimulating properties of an odor, hence
432 the commonly use of the former for a proxy of the latter (Anderson et al., 2003; Lewis et al.,
433 2007; Winston et al., 2005).

434 Interestingly, however, relaxing judgements did not follow an inverse pattern with
435 regards to stimulating judgements, as would have been expected within a bidimensional
436 model. Instead, we found that for odors *a priori* considered “relaxing” (i.e., strawberry and
437 lavender), relaxing judgments also increased with increasing stimulus concentration. At the
438 highest concentrations, these odors were even perceived as much relaxing as stimulating. In
439 other words, there were positive, not opposite, relations between relaxing and stimulating
440 scales for considered relaxing odors (i.e., strawberry and lavender). These somewhat
441 paradoxical results are however consistent with frameworks considering relaxing and
442 stimulating properties as two independent dimensions (Chrea et al., 2009; Ferdenzi et al.,
443 2011; Porcherot et al., 2010). Such a positive relationship between relaxing and stimulating
444 scales are hard to reconcile with theories considering the activation properties of odors as one
445 unified bipolar dimension opposing relaxing to stimulating labels (Feldman Barrett & Russell,
446 1998; Russell, 1980; Russell et al., 1989). Furthermore, relaxing judgments for odors
447 commonly considered as “stimulating” (i.e., coffee and lemon) were not significantly
448 influenced by the variations of concentration. Indeed, there were no negative correlations
449 between relaxing and stimulating scales for these odors. Taken together, the current results
450 suggest that relaxing and stimulating judgments should benefit from being considered as two
451 distinct concepts rather than as extremes of a single dimension. Accordingly, these findings
452 emphasize the need to use two independent unipolar scales in self-reports questionnaires
453 when one wants to measure the relaxing and stimulating properties of odors. Further
454 researches could for example investigate whether our results could be extended to other
455 sensory modalities, especially with food-related emotions since the bidimensional theoretical
456 framework still remains predominant and valence still being the most investigated dimension
457 (den Uijl, Jager, Zandstra, de Graaf, & Kremer, 2016; Jaeger et al., 2018; Kaneko et al., 2018,
458 2019; Toet et al., 2018).

459 Our observations also disqualify the usual view, which considers intensity as a proxy
460 for emotional arousal, at least for relaxing properties within the olfactory domain. In the
461 current study, both strawberry and lavender were still perceived as relaxing at the strongest
462 concentration, suggesting that the relationship between the relaxing properties of odors and
463 stimulus concentration is neither direct nor systematic. Our findings thus suggest that to
464 assimilate the odor intensity to its arousal properties could be misleading depending on the
465 odor at hand, especially for relaxing judgments. It is worth mentioning that a similar pattern is
466 not limited to olfactory-perceived emotions and can be found for other sensory modalities. In
467 music for instance, intensity (i.e., loudness) is generally considered as a proxy for the arousal
468 dimension. The arousing effect of loudness has recently been shown on explicit affective
469 ratings (Karageorghis, Cheek, Simpson, & Bigliassi, 2018). More precisely, louder musical
470 excerpts led participants to report higher scores on the Russell's Affect grid (Russell et al.,
471 1989) compared to soft music or no-music control conditions. However, soft music was not
472 associated with lower score on the Affect grid compared to no-music control condition,
473 indicating that soft music was not necessarily considered as relaxing whereas loud music was
474 strongly associated with stimulating properties. Altogether, these results mirror our findings
475 showing that the intensity/arousal relation may be valid for stimulating judgments but is
476 uncertain when it comes to relaxing properties.

477 We also found that the relaxing ratings of the lemon odor did not vary with
478 concentration and were distributed around medium values, below the stimulating ratings for
479 higher concentrations, but strikingly *above* them at the lower concentrations (see figure 1).
480 The analysis of individual rating profiles showed that most participants answers corresponded
481 to three different profiles: 1) an increase in both relaxing and stimulating ratings with
482 concentration, 2) a cross-shaped ratings showing a shift from relaxing to stimulating
483 perceived property with increasing concentration, 3) a n-shaped relaxing ratings and a rise of

484 stimulating ratings (see Figure 2 for the three main profiles, and for more details, see Figure
485 S6 of the supplementary material). Similar shifting patterns have been previously interpreted
486 in terms of pungency of the odorant (Jin et al., 2018). However, in the present study, the very
487 low ratings of perceived pungency (with a good interrater agreement) associated to our lemon
488 odor at all odorant concentrations preclude a similar interpretation of our results. Future
489 studies should closer examine the relationship between odorant pungency, odor perceived
490 pungency and relaxing and stimulating properties to inform our understanding of olfactory
491 perceived emotions.

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

509 who are not afraid of the dentist (Alaoui-Ismaïli, Robin, Rada, Dittmar, & Vernet-Maury,
510 1997). Moreover, in the same study, this odor was negatively judged only by fearful subjects,
511 illustrating how very specific can individual experience of olfactory-elicited emotions be.

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

532 In this regard, it is plausible that many of the previously reported discrepancies in self-
533 reports measures of relaxing and stimulating properties of odors stemmed also from

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

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

558 determine whether low intensities of lemon are implicitly associated to relaxing properties
559 and high intensities to stimulating properties.

560 However, our study presents a few limitations that deserve to be discussed. It is known
561 that odor quality can sometimes depend on concentration for a same odorant. For instance,
562 alpha-ionone smells of violet at low concentration but of cedar wood at high concentration
563 (Sengupta, Colbert, Kimmel, Dwyer, & Bargmann, 1993). As mentioned above, odor
564 intensity is considered as one parameter influencing odors perception-based arrangements,
565 listed by Kaeppler and Mueller (2013, see “odorant factor”). As described by these authors,
566 the intensity of an odor can change its proper quality (Gross-Isseroff & Lancet, 1988; Laing,
567 Legha, Jinks, & Hutchinson, 2003) as opposed to color perception where intensity does not
568 change the basic hue quality. From this point of view, a limitation of our study is that we did
569 not make sure that odors quality did not change with concentration, but this was a
570 methodological choice since explicitly asking participants to describe and/or identify all the
571 presented samples would have biased spontaneous answers via explicit suggestion effects for
572 a same odorant and maybe between them (aside from the fact that it would have significantly
573 impacted study length and probably participants implications in their task). Change in quality
574 depending on odorant concentration poses interesting theoretical questions since
575 concentration could activate distinct representations retrieved from episodic memory
576 (potentially acquired from previous associative-learning). In olfaction, it is paramount to
577 consider intensity as a dimension in affective response to odorants and not as a distinct
578 dimension outside the affective space nor equivalent to a solitary quality dimension (Henion,
579 1971). As recommended also by Kaeppler and Mueller (2013), future researches should not
580 only control for intensity of several odors by using equally intense stimuli from a pretest as is
581 generally done, but they should also pretest several concentrations of a given odorant in order
582 to check for misrepresentation of odors quality at every intensity level, since some odors may

583 not have a single position within the olfactory space (Kaepler & Mueller, 2013). But
584 challenging methodological issues should first be solved, by using for example the above-
585 mentioned IAT or indirect sorting or non-verbal matching tasks (preferably in experimental
586 sessions temporally separated from explicit property ratings). Moreover, it might be important
587 to use only one single odorant per experimental session.

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

599

600 5. Conclusions

601 In conclusion, our findings showed (1) a systematic link between concentration of
602 chemical stimulus, odor perceived intensity and stimulating judgments for all odors, (2) a link
603 between concentration of chemical stimulus, odor perceived intensity and relaxing judgments
604 for *a priori* relaxing odors (i.e., strawberry and lavender) but not for *a priori* stimulating ones
605 (e.g., coffee), and (3) a tendency to shift from relaxing at low concentration to stimulating at
606 high concentrations for some odor (i.e., lemon). In the past, many researches on odors, flavors
607 and aroma appreciation might have led to inconclusive and/or inapplicable results because the

608 relaxing and stimulating properties of olfactory stimuli were not considered as two separate,
609 affective dimensions, but rather as two opposite labels of a single one. As a first step, it was
610 decided here to select four odors in order to have a better representation of relaxing and
611 stimulating odors categories and five concentrations for a better sensitivity to odorant
612 concentration manipulation. Overall, the current results stress the need to rely on separate
613 unipolar scales when assessing the relaxing and stimulating properties of odors and encourage
614 further studies, whether fundamental or applied, to integrate the use of different stimulus
615 concentrations in experimental designs.

616

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621

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- 893

894 **Tables captions**

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

897

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

900

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

903

904 **Figures captions**

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

907

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

910
911 *Figure 3.* Mean Value of Familiarity and Pleasantness Ratings on a Visual Analog Scale (VAS) for
912 Each Odor at Each Concentration. Error Bars Indicate Standard Error of the Mean.

913

914 **Tables**915 **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

916

917 **Table 2.** Means and Standard Deviation of the Intensity Ratings on a Visual Analog Scale
918 (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

919

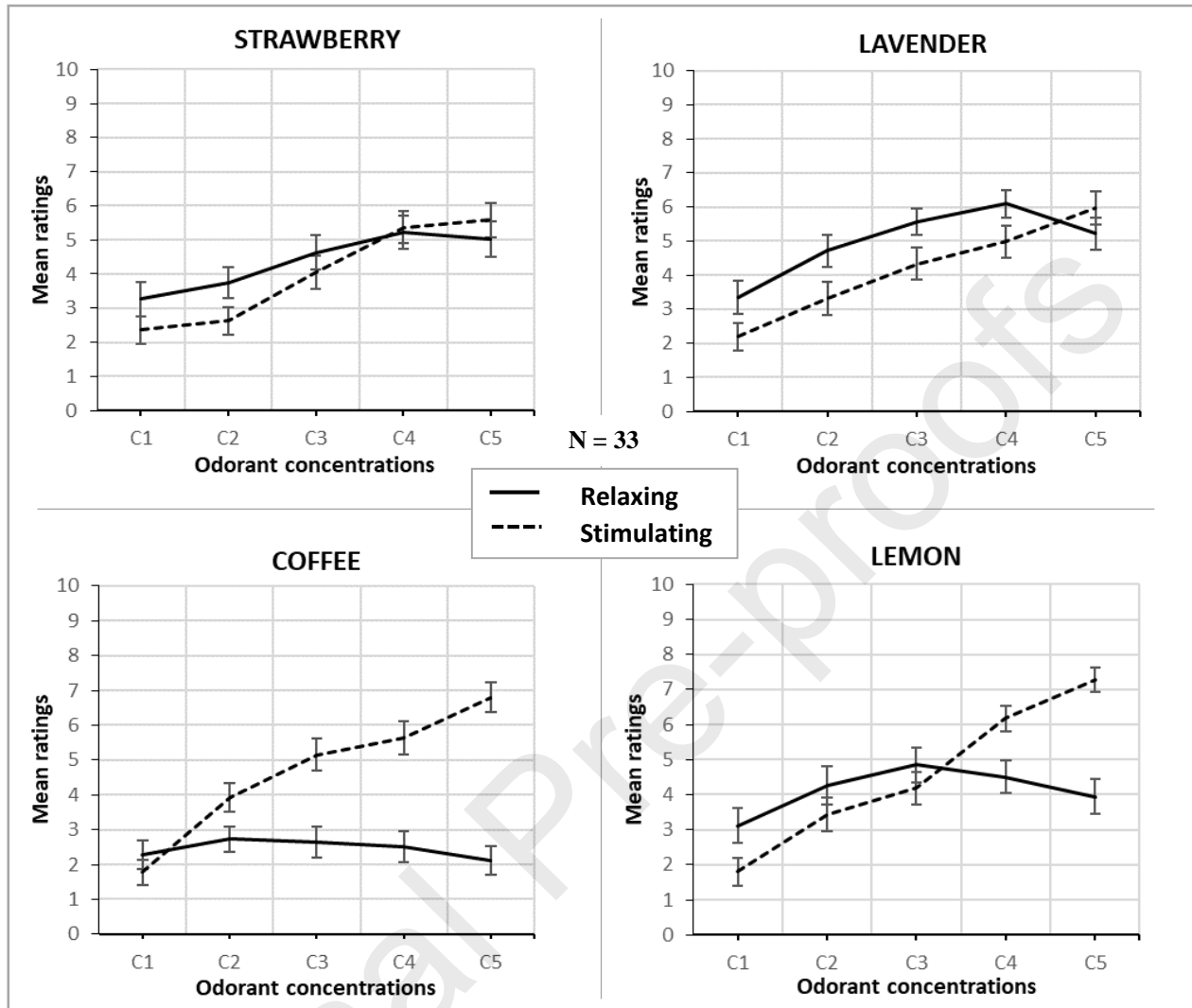
920 **Table 3.** Mean Values of Difference Between Stimulating and Relaxing Ratings and *p*-values
921 from Test of Means Against Zero as Reference Constant Value.

Concentration	COFFEE		LEMON		STRAWBERRY		LAVENDER	
	Mean (SD)	<i>p</i> -value	Mean (SD)	<i>p</i> -value	Mean (SD)	<i>p</i> -value	Mean (SD)	<i>p</i> -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

922 **p* < .05

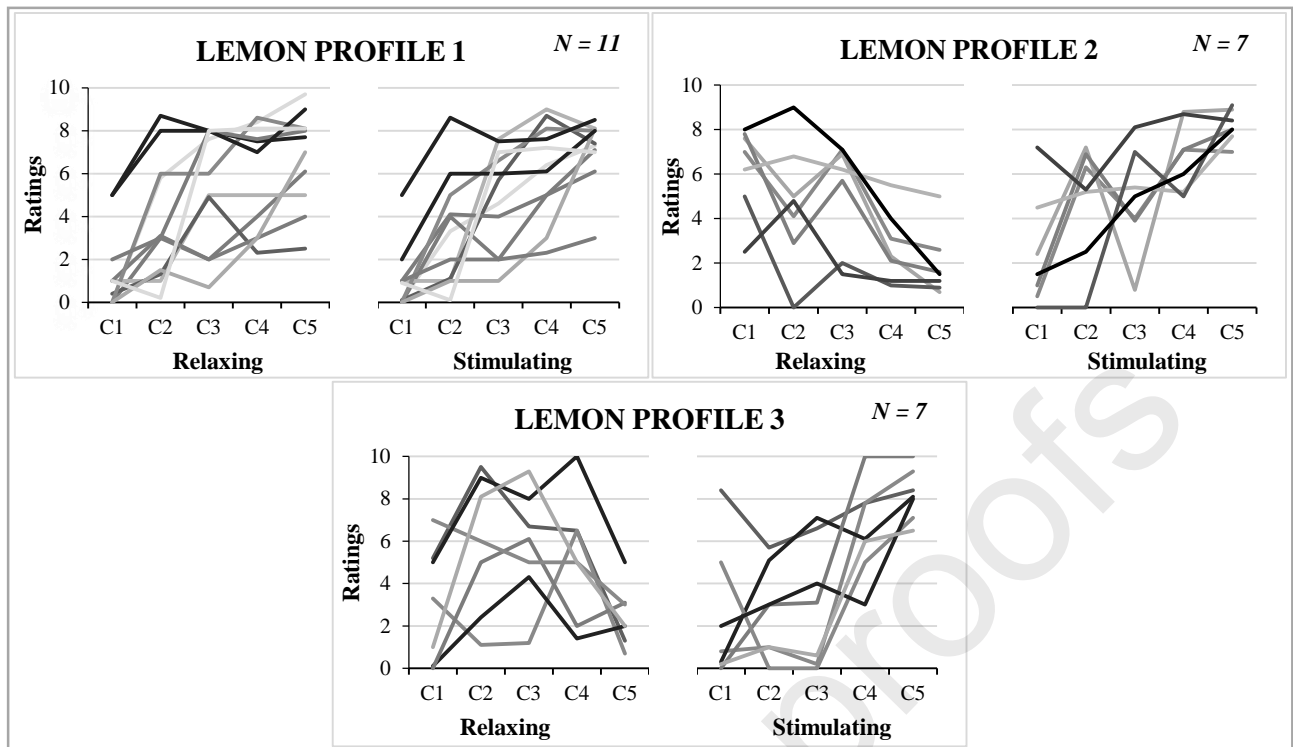
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924 **Figures**



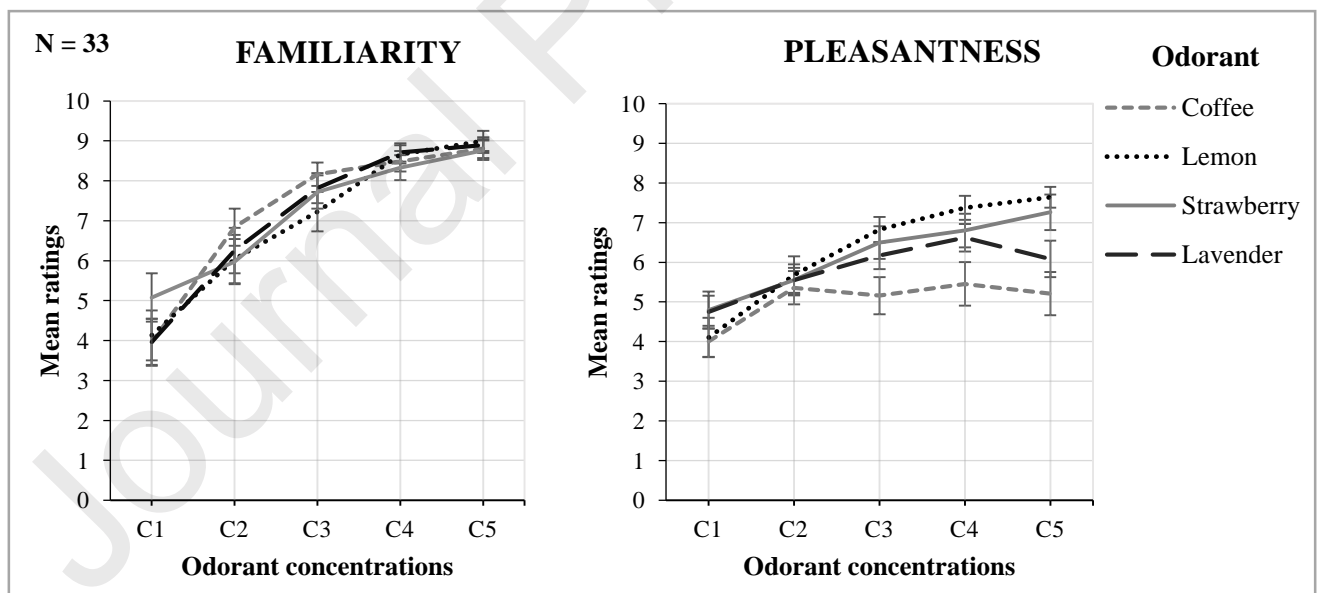
925

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



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

930
 931



932
 933 *Figure 3.* Mean Value of Familiarity and Pleasantness Ratings on a Visual Analog Scale (VAS) for
 934 Each Odor at Each Concentration. Error Bars Indicate Standard Error of the Mean.

935

936

937 **Highlights**

- 938
- All odors are judged more and more stimulating with increasing stimulus concentration.
- 939
- Some odors are also judged increasingly relaxing with stimulus concentration.
- 940
- Relaxing and stimulating labels should not be considered as two extremes of a single
- 941
- “arousal” dimension.
- 942

943

944 **Authors statement**

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

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