

1 **Smelling sensations: olfactory crossmodal correspondences**

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9 **Abstract**

10 Crossmodal correspondences are the associations between apparently distinct stimuli in different
11 sensory modalities. These associations, albeit surprising, are generally shared in most of the population.
12 Olfaction is ingrained in the fabric of our daily life and constitutes an integral part of our perceptual
13 reality, with olfaction being more commonly used in the entertainment and analytical domains, it is
14 crucial to uncover the robust correspondences underlying common aromatic compounds. Towards this
15 end, we investigated an aggregate of crossmodal correspondences between ten olfactory stimuli and
16 other modalities (angularity of shapes, smoothness of texture, pleasantness, pitch, colours, musical
17 genres and emotional dimensions) using a large sample of 68 observers. We uncover the
18 correspondences between these modalities and extent of these associations with respect to the explicit
19 knowledge of the respective aromatic compound. The results revealed the robustness of prior studies,
20 as well as, contributions towards olfactory integration between an aggregate of other dimensions. The
21 knowledge of an odour's identity coupled with the multisensory perception of the odours indicates that
22 these associations, for the most part, are relatively robust and do not rely on explicit knowledge of the
23 odour. Through principal component analysis of the perceptual ratings, new cross-modal mediations
24 have been uncovered between odours and their intercorrelated sensory dimensions. Our results
25 demonstrate a collective of associations between olfaction and other dimensions, potential cross modal
26 mediations via exploratory factor analysis and the robustness of these correspondence with respect to
27 the explicit knowledge of an odour. We anticipate the findings reported in this paper could be used as
28 a psychophysical framework aiding in a collective of applications ranging from olfaction enhanced
29 multimedia to marketing.

30 Introduction

31 Olfaction is ingrained into the fabric of our lives, altering the very perception of our favourite
32 commodities and plays a crucial role in the multi-sensory perception of our surrounding environment.
33 Exploring the crossmodal correspondences provided by the chemical senses is pivotal towards solving
34 the crossmodal binding problem, and in turn, their implication on interactive and immersive
35 experiences. Crossmodal correspondences can be depicted as the consistent correspondence between
36 stimulus features in different sensory modalities [1]. These correspondences can be matched if they
37 both have the same effect on the observers' mood, emotional state, alertness and/or arousal [1–3].
38 Aromas are consistently perceived together with other stimuli principally visual, the absence of these
39 additional stimuli results in inferior identification [4,5]. Albeit, semantic congruency can enhance the
40 perceived pleasantness [6,7], discrimination [8] and correct identification of odours [9]. Crossmodal
41 correspondences have been shown to induce a bias (i.e., providing a red glass of white wine can bias
42 the judgment of expert wine tasters [10]). In terms of evolution, olfaction is one of the oldest senses and
43 plays a major role in social behaviour, communication and emotional evaluation; mood and emotional
44 processes share a common neural substrate with the olfactory pathway, namely the limbic system [11].
45 It is therefore likely that olfactory information plays a major role in modulating the quality of our
46 immersive multisensorial experiences.

47 Crossmodal interactions between smell and both vision and hearing have been of distinct
48 interest, as it has been shown to alter olfactory perception considerably. For example, olfaction-audition
49 [12–14], olfaction-colour [15–18], olfaction-visual motion [19], and olfaction-angularity of shapes
50 [18,20]. The mechanisms underlying such correspondences has diverse characterisation within the
51 literature. The most frequently deduced mechanisms are; hedonics [14,20–23], semantics [1,18,22,24–
52 27] and natural co-occurrence [1,27,28]. Identifying robust crossmodal olfactory associations has a
53 vast array of practical implications spanning from advertising to human-computer interaction. A
54 contributory factor to idiosyncratic, as opposed to robust associations, is the relatively high inter-
55 observer variability of the olfactory sense [29]. There is an increasing demand to provide the chemical

56 senses to human-machine interfaces, as modern technology is typically limited to vision, auditory and
57 basic haptic feedback. Understanding how the chemical senses interact with the other senses and their
58 implication on interactive and immersive experiences is the next step towards total sensory immersion
59 and augmenting artificial synaesthesia to expand and create new senses for humans.

60 Synaesthesia is a neurological condition in which input into one modality elicits a simultaneous
61 perception in a second modality [30]. Controversially, synaesthesia could be considered a more severe
62 manifestation of crossmodal associations [26] and antagonistically [31]. It is hypothesized that everyone
63 is born with synaesthesia [32] but is later disinhibited [33] and/or pruned. Synaesthesia can still provide
64 valuable information on the initial hypothesis between the strong intercorrelated sensory dimensions
65 and their potential in cross modal correspondences despite the automatic evocation.

66 We hypothesize that there will be robust associations that are mediated predominantly by
67 hedonic ratings underlying common aromatic compounds. These associations could, at least in part, be
68 affected by knowledge of the odour's identity. We provide evidence to support both hypotheses, we
69 explored a series of potential crossmodal correspondences. Here we present associations between
70 olfactory stimuli and the angularity of shapes, colour, smoothness of textures, pitch, musical genres,
71 and several emotional dimensions. We further investigate whether explicit knowledge of the odours
72 modulates these associations by using an odour identification task. Exploratory factor analysis was then
73 conducted on the perceptual ratings, revealing potential crossmodal mediations and the perceptual
74 similarity between the ten aromatic compounds used in these experiments.

75 **Materials & methods**

76 **Participants**

77 68 individuals (23 males and 45 females with a mean age of 26.75 (standard deviation: 12.75))
78 took part in the experiments. No participants reported any impairment that could affect their sense of
79 smell (i.e., cold or flu). Participants were briefed about potential allergens and breaks (a minimum of a
80 10-minute break halfway through, or if the participant felt like they have got a reduced sense of smell).
81 The experiment was given ethical approval by the University of Liverpool, lasted approximately 50
82 minutes and conducted in accordance to the standards set in the Declaration of Helsinki for Medical
83 Research Involving Human Subjects. Participants gave written informed consent before taking part in
84 the experiment.

85

86 **Apparatus**

87 All results were obtained through a graphical user interface programmed in MATLAB R2018b.
88 Participants were placed in a lightproof anechoic chamber equipped with an overhead luminaire (GLE-
89 M5/32; GTI Graphic Technology Inc., Newburgh, NY) during the experiment. The lighting in the room
90 was kept consistent by using the daylight simulator of the overhead luminaire. The speakers were JBL
91 Desktop speakers; the colour stimuli were shown on a calibrated EIZO ColorEdge CG243W monitor.

92

93 **Tasks and Stimuli**

94 Participants were instructed to associate a given odour with a value along each of the following
95 dimensions: visual shapes, textures, pleasantness (using a 1 scale), pitch, music genre and emotions.
96 The aromas were presented in a random order (determined by a random number generator in MATLAB)
97 and all associations were assessed in the same order for a given aroma. At the end of the experiment,

98 participants were asked to identify the odour (identification task). For three of the experimental tests
99 (visual shapes, texture, pleasantness) and for the emotion task a neural option was available, but
100 participants were strongly discouraged to use this option.

101 **Odour Stimuli**

102 Ten odourants were used; five from Mystic Moments™; caramel, cherry, coffee, freshly cut
103 grass, and pine; five from Miaroma™; black pepper, lavender, lemon, orange and peppermint. These
104 aromas were selected as they can be frequently found during everyday life and gives diversity in the
105 chemical makeup of the aromas. For consistency and to avoid any other associations that would affect
106 the results of this experiment 4 mL of the respective essential oil was placed in a clear test tube, wrapped
107 in white tape and numbered 1 through 10 in an initial random permutation. The aromas were stored at
108 $\approx 2.5^{\circ}\text{C}$ to minimize oxidation, all odours were removed and placed back into the fridge at the same
109 time to ensure approximately uniform evaporation. The odours were replaced every two weeks.

110 **Shape Stimuli**

111 A nine-point scale was constructed with a rounded shape “bouba” and an angular shape “kiki”
112 on the left and right side of the scale respectively. Similar to an earlier experiment performed by [20].
113 The midpoint of the nine-point scale (5) was neutral (no opinion).

114 **Texture Stimuli**

115 A nine-point scale was constructed with smooth and rough anchored on the left and right side
116 respectively. Participants were supplied with representative textures to aid them in their decision, with
117 silk being a representative for smooth and sandpaper being a representative for rough. The midpoint of
118 the nine-point scale (5) was neutral (no opinion). Participants felt the texture at least once during the
119 questions' first appearance.

120 **Pleasantness**

121 A nine-point scale from very unpleasant to very pleasant was used, with 5 being the neutral
122 option.

123 **Pitch Stimuli**

124 The full range of audible frequencies (20Hz to 20kHz) was implemented using a slider where
125 movement from left to right corresponded to an increase in frequency. Every time the slider was
126 adjusted the respective frequency was played, producing a sinusoidal tone lasting 1 second in length.
127 Due to the large volume of potential selections, participants were played a sample from each end of the
128 scale, followed by a sample at 10kHz, if the current pitch didn't match the odour a lower or higher pitch
129 was selected (approximately half way between the last two frequencies played) as indicated by the
130 participant.

131 **Music Stimuli**

132 Seven different music genres; classical, country, heavy metal, jazz, rap, classic rock, and soul.
133 Five were selected from [34] with an additional two added due to their wide popularity. Each sample
134 was 15 seconds in duration and played at the same volume across participants. Participants had to listen
135 to each sample at least once during the questions first occurrence, the order was subject to the
136 participants preference.

137 **Colour Stimuli**

138 The CIE L*a*b* colour space was used because of its perceptual uniformity, participants could
139 slide through 101 linear interpolated slices from the L* channel of the colour space increasing or
140 decreasing the lightness. Only colours that fit in sRGB colour gamut were shown. This removed the
141 limitations of earlier studies that let participants choose from a small selection of colours.

142 **Emotions**

143 A subset of emotions from the Universal Emotion and Odour Scale [9] was included these
144 where; angry, aroused, bored, calm, disgust, excited, happy, sad and scared, additionally an option for
145 neutral (no opinion) was added to negate a tentative assignment.

146 Identification Task

147 A list of different aromas was compiled consisting of the ten odours used in this experiment
148 along with an additional fifteen and presented in alphabetical order. This was incorporated to increase
149 the number of choices the participant had available, so they were less likely to make inferred decisions
150 when trying to identify the current odour. The identification task was at the end of the experiment.

151

152 Results

153 Angularity, smoothness, pleasantness and pitch

154 Fig 1 shows the mean ratings (transformed to z-scores) for angularity, smoothness, pleasantness
155 and pitch for each of the 10 odours. Friedman tests were conducted on the z-scores of the angularity,
156 smoothness, pleasantness and pitch ratings to test if the odours influenced the ratings. This revealed
157 that the odours significantly affected all ratings; angularity ($\chi^2(9) = 122.15, P < 0.05$), smoothness ($\chi^2(9)$
158 $= 52.32, P < 0.05$), pleasantness ($\chi^2(9) = 81.85, P < 0.05$) and pitch ($\chi^2(9) = 101.75, P < 0.05$). A
159 Bonferroni multiple comparison test was conducted to identify which odours were significantly
160 different from each other. A post-hoc one sample t-test with a Bonferroni correct alpha was conducted
161 to determine which of the odours was significantly different from 0 (the original scale's grand mean).
162 The significantly 'rounded' odours are caramel ($P < 0.005, t = -9.88$) and coffee ($P < 0.005, t = -3.87$).
163 The significantly 'angular' odours are peppermint ($P < 0.005, t = 8.62$) and lemon ($P < 0.005, t = 3.43$),
164 as shown in Fig 1A. The significantly 'rough' odour is black pepper ($P < 0.005, t = -3.22$) the
165 significantly 'smooth' odour is caramel ($P < 0.005, t = 4.64$), as shown in Fig 1B. The significantly
166 'pleasant' odours are lemon ($P < 0.005, t = 4.27$) and orange ($P < 0.005, t = 6.87$). The significantly

167 ‘unpleasant’ odour is black pepper ($P < 0.005$, $t = -5.84$), as shown in Fig 1C. The significantly ‘higher
168 pitch’ odour is peppermint ($P < 0.005$, $t = 3.47$). The significantly ‘lower pitch’ odours are coffee ($P <$
169 0.005 , $t = -5.64$) and caramel ($P < 0.005$, $t = -4.60$), as shown in Fig 1D.

170

171 **Fig 1. Shape, texture, pleasantness and pitch scores.** (A – C) Mean scores for the 10 odours after z-
172 score normalisation using the grand mean, asterisks mark the odours that are significantly different from
173 the scale’s original grand mean. Errors bars show a 95% confidence interval of the respective odour.
174 The legend shows markers indicating which odours have significantly different means from the
175 respective odour (e.g., the significantly different odours from coffee in (A) are lemon, peppermint and
176 pine. (D) Shows the same information as (A – C) apart from the mean value used to calculate its z-score
177 is that of log₂ of the original ratings.

178

179 **Genre and emotions**

180 To assess if odours affected the genre and emotion selections chi-squared tests of independence
181 were conducted. This revealed that the odours impact both the choice of genre ($\chi^2 = 138.20$, $P < 0.05$)
182 and participants emotional response ($\chi^2 = 187.54$, $P < 0.05$). Consequently, chi-squared tests for
183 goodness of fit were conducted to see which of the presented stimuli were significantly different from
184 a chance selection. The odours that were significantly different from a chance selection in the genre
185 association task are black pepper, caramel, cherry, coffee, freshly cut grass, lemon and orange ($P <$
186 0.05) (See Fig 2A). The odours were significantly different from chance selection in the emotion
187 association task ($P < 0.05$) (See Fig 2B).

188

189 **Fig 2. Musical genre and emotional association matrices.** (A) Association matrix between the 10
190 odours and the 11 possible emotional selections. (B) Association matrix between the 10 odours and
191 the 7 genres.

192

193 Colours

194 Due to many possible colour choices, 343 interpolated colours from L*a*b* colour space were
195 chosen (See Fig 3A). The colour the user had selected was then mapped to one of the 343 colours based
196 on the lowest delta E 2000 error to determine the perceptually closest colour. This was consequently
197 used as the representative selection, shown in Fig 3B. The median hue angle for the commonly selected
198 colours is shown in, Fig 3C. Each participant only reported one colour for each odour. A one-way t-
199 tests (test value = 50) was conducted with a Bonferroni corrected alpha of 0.005 (0.05 / 10) to determine
200 if the selected lightness values were significantly different from the range's midpoint and default slice
201 of 50. The significantly different odours are; (where L^* represents the mean lightness score from the
202 L*a*b* colour space) caramel ($P < 0.005$, $t = 4.30$, $L^* = 59.78$), cherry ($P < 0.005$, $t = 3.66$, $L^* =$
203 58.14), coffee ($P < 0.005$, $t = -2.18$, $L^* = 44.73$), freshly cut grass ($P < 0.005$, $t = 3.47$, $L^* = 56.91$),
204 lavender ($P < 0.005$, $t = 4.82$, $L^* = 60.11$), lemon ($P < 0.005$, $t = 15.10$, $L^* = 76.51$), orange ($P <$
205 0.005 , $t = 12.53$, $L^* = 70.10$), peppermint ($P < 0.005$, $t = 7.5$, $L^* = 66.35$) and pine ($P < 0.005$, $t = 3.71$,
206 $L^* = 58.68$). A chi-square test of independence was conducted on the hue angles of the colours. Due to
207 the large number of possible angles binning was implemented ($N = 15$), a chi-square test for goodness
208 of fit was conducted on the binned hue angles to see if the colours selected differ from chance selection,
209 this revealed the colour selections for each odour significantly differ from chance selection ($P < 0.005$).

210

211 **Fig 3. Commonly selected colours and median hue angles.** (A) L*a*b* colour gamut showing the
212 interpolated points used to determine the perceptually closest colour. (B) Common colours selected by
213 the participants where each colour has been mapped more than twice. (C) Cylindrical representation of
214 the L*a*b* colour space showing the median hue angle of the commonly selected hues for each odour

215

216 Identification dependencies

217 To determine if the proportions (correct and incorrect) were significantly different, chi-
218 squared tests for goodness of fit were conducted this revealed that the proportions for black pepper (x^2
219 = 85.76, $P < 0.05$), caramel ($x^2 = 47.05$, $P < 0.05$), coffee ($x^2 = 7.52$, $P < 0.05$), freshly cut grass ($x^2 =$
220 19.88, $P < 0.05$), lemon ($x^2 = 51.88$, $P < 0.05$), orange ($x^2 = 7.52$, $P < 0.05$), peppermint ($x^2 = 56.94$,
221 $P < 0.05$), and pine ($x^2 = 73.52$, $P < 0.05$) varied significantly. To assess if the variation between correct
222 and incorrect identification was statically significantly a two-way ANOVA was conducted for each
223 odour. This revealed that there was no significant variation for the angularity ratings (see Fig 4A), the
224 significant odours for the smoothness ratings are lavender ($P < 0.05$) and caramel ($P < 0.05$) (see Fig
225 4B). The significant odours for the pleasantness ratings are lavender ($P < 0.05$) and peppermint ($P <$
226 0.05) (see Fig 4C) with the latter also being significant in the pitch ratings (see Fig 4D).

227

228 **Fig 4. Angularity, smoothness, pleasantness and pitch identification dependencies.** Mean z-scores
229 asterisks denote odours where there is significant variation between the correct and incorrect ratings.
230 The green markers denote correct classification and the red markers denote incorrect classification.
231 The error bars show a 95% confidence interval.

232

233 To assess if explicit knowledge of the odour affected the emotional and genre dimensions the
234 relative difference between correct and incorrect identification was calculated for each odour. Fig 5A
235 shows that the knowledge of an odour does affect the emotional dimensions and has Frobenius norm of
236 323.06. Peppermint, for example, was perceived as less happy and angrier. Generally, the odours were
237 perceived as being more neutral, calming and slightly disgusting. From Fig 5B we can see that
238 knowledge of the odours affects the genre dimensions, for example, peppermint is perceived to be less
239 jazz and more metal and rap the genre association matrix has a Frobenius norm of 339.70.

240

241 **Fig 5. Relative musical genre and emotional association matrices.** (A) Relative association matrix
242 between the 10 odours and the 7 genres. (B) Association matrix between the 10 odours and the 11
243 possible emotional selections.

244

245 Following the same procedure as the colour analysis above, common colours for the
246 misclassified odours are shown in Fig 6. To determine if the observed proportions between the common
247 colours and the common misclassified colours were significantly different, chi-squared tests for
248 goodness of fit were conducted this revealed that the proportions for cherry ($x^2 = 14.00$, $P < 0.05$),
249 coffee ($x^2 = 7.77$, $P < 0.05$), lavender ($x^2 = 4.28$, $P < 0.05$), lemon ($x^2 = 18.00$, $P < 0.05$), orange ($x^2 =$
250 10.50 , $P < 0.05$) and peppermint ($x^2 = 14.00$, $P < 0.05$) are significantly different. The same pattern is
251 observed for correct and incorrectly identified odours, which is consistent with the idea that crossmodal
252 correspondences between olfaction and colour do not rely on explicit knowledge of the odour's identity.

253

254 **Fig 6. Common colours for misclassified odours.** Common colour selections where each colour has
255 been incorrectly classified and been mapped more than twice.

256

257 **Identification**

258 The task of participant was to identify the given odour by selecting one of the 25 possible
259 odours in the list. Retrospectively, a twofold identification was considered, exact identification and
260 categorical identification. Exact identification was achieved 45.74% of the time by correctly identifying
261 the current odour, participants could select an odour label from a compiled list of 25 different odours.
262 The top three correctly identified odours are peppermint (84.21%), lemon (80.88%) and orange
263 (63.16%). The top three misclassified odours are black pepper (10.29%), pine (12.24%) and caramel
264 (20.59%) (see Fig 7). Retrospective category identification was determined by the participants' ability
265 to pick another odour in the same category following the fragrance classes outlined in [35]. An accuracy

266 rating of 62.94% was achieved for category identification, each potential classification belonged to only
267 one category. A Pearson correlation indicated that there was no strong correlation between the age of
268 the participant and their identification accuracy ($P = -0.17$).

269

270 **Fig 7. Identification association matrix.** Association matrix for the 10 odours, along with an additional
271 12 misclassifications.

272

273 **Principal component analysis**

274 Factor analysis using Principal Component Analysis (PCA) was conducted on; the shape
275 ratings, texture ratings, pleasantness ratings, pitch ratings, identification accuracy, the colour dimension
276 (lightness), the emotional dimensions and the genre dimensions. Due to the ratings and dimensions
277 being on different scales z-score normalisation using the odour-wise mean and the standard deviation
278 on the original dataset before PCA. Based on inspection of the score plot, four principal components
279 were kept, explaining 81.57% of the total variance and have an eigenvalue of at least 1. The principal
280 components 1 through 4 explain 32.49%, 25.60%, 14.43% and 9.04% of the total variance respectively.
281 The first two principal components are shown in Fig 8A with the loading matrix, shown in Fig 8B.

282

283 **Fig 8. PCA score and loadings.** (A) Score plot of the perceptual ratings for each odour. (B) Loading's
284 plot showing the covariance coefficients for each of the dimensions used in the PCA.

285

286 **Discussion**

287 Our results further our understanding of crossmodal processing and how olfactory sensations
288 interact with the perception of angularity of shapes, smoothness of textures, perceived pleasantness,

289 pitch, genre and emotions. Our first hypothesis was that robust associations exist for common aromatic
290 compounds and we find evidence for such associations, consistent with prior findings; olfactory
291 associations between the angularity of shapes [20], smoothness of texture [36] and pitch [12] suggesting
292 that the hedonic qualities are important factors in crossmodal correspondences. Our second hypothesis
293 was that knowledge of a odours identity would affect some of the reported associations, consistent with
294 the findings reported by [18] between odours and colours and angularity of shapes. Odours produce
295 reliable and distinct colour profiles, which are more consistent with the explicit knowledge of an odour's
296 identity. Furthering these findings, we show the reliability and extent of these associations, and that the
297 knowledge of an odour's identity partly affects their reported associations between the other modalities
298 with the exemption of the angularity of shapes.

299 The PCA analysis score plot shows the perceptual similarity between the olfactory stimuli, for
300 example, (lemon, cherry and orange), (lavender, freshly cut grass and pine), (coffee and caramel)
301 obtained similar results in most, but potentially not all, ratings analysed using PCA. The PCA loadings
302 plot suggests that the hedonic values are a strongly influenceable factor, that is, the strong loadings of
303 the pleasant (i.e., happy, excited and calm), unpleasant (i.e., sad, angry and scared) and the 'pleasantness
304 dimension' are at least moderately associated to the other dimensions reported in this paper.
305 Additionally, the loadings plot shows strong associations between the angularity of shapes, textures,
306 pitch, emotional and genre dimensions. Odours judged to be the rounded shape tend to be associated
307 with a smooth texture, be lower in pitch, be more soul. Whereas, the angular shape appears to be
308 strongly associated with the genre dimension rock. Moderate associations exist between the angularity
309 of shapes with the angular shape being associated with lighter colours, being more rap, angry, arousing
310 and exciting. Strong associations exist between the odours and the smoothness ratings with smooth
311 being perceived as more soul, happier and less angry. Moderate relationships exist with smooth being
312 perceived as more pleasant, lower in pitch and being more country. With the rough texture being
313 associated to be more metal, rock, neutral, sad and angry. The strong associations between pleasant
314 odours are being less metal, disgusted and being happier. With moderate relations being more excited,
315 soul, less sad, easier to identify with an increase in lightness. Higher pitches are strongly associated

316 with being lighter in colour and being more rock with moderate relations to being more exciting,
317 arousing, rap, and being less soul. Darker colours are moderately associated with being more metal and
318 disgusted while lighter colours are moderately associated with being more rock and exciting. The strong
319 associations between the odours and identification rate are being more happy, exciting and being less
320 sad and disgusting. Moderate relationships exist between a higher identification rate and being more
321 jazz and less metal, classical, neutral, disgusting and boring. All relationships uncovered in the PCA
322 analysis can also be applied in reverse (i.e., the odours perceived as being smoother are generally
323 assigned to being less angular and more rounded in shape). Consistent with the findings from [37], The
324 PCA shows strong relationships towards the emotional and musical dimensions, for example, the
325 relationships between the emotion ‘happy’ are being less more jazz and soul and less metal. The
326 relationships between ‘angry’ are being more metal and less soul.

327 Future work stemming from these findings could include assessing if congruent vs incongruent
328 associations defer any advantages in an objective task. The moderate relations discovered in the PCA
329 analysis, between odours and the different relationships could be explored further with a more tailored
330 set of experiments. The cross-model mediations (i.e., the intercorrelated dimensions) uncovered during
331 the PCA may be explored further to uncover the robustness of the associations. Additional sensory
332 dimensions could be added, gustatory could be explored, towards the goal of an olfactory
333 psychophysical framework, to aid in a variety of different applications ranging from olfaction enhanced
334 multimedia to marketing. Due to the nature of olfaction, it may be the case that taste played a minor
335 role in the associations reported in this paper. For example, [38] reported the bitter tastes were
336 associated with angular shapes, whereas, sweet tastes are associated with a more rounded shape. In
337 contrast with a later study, [20] reported a strong association between the angularity of shapes and the
338 perceived sourness/bitterness of odours.

339

340 **Author contributions**

341 RJW and SMW conceived and designed the experiments. RJW performed the experiments.
342 RJW and SMW analysed the data. AM and SMW contributed reagents. RJW programmed the analysis
343 tools. SMW and AM provided supervision. RJW, SMW and AM wrote the paper.

344

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431

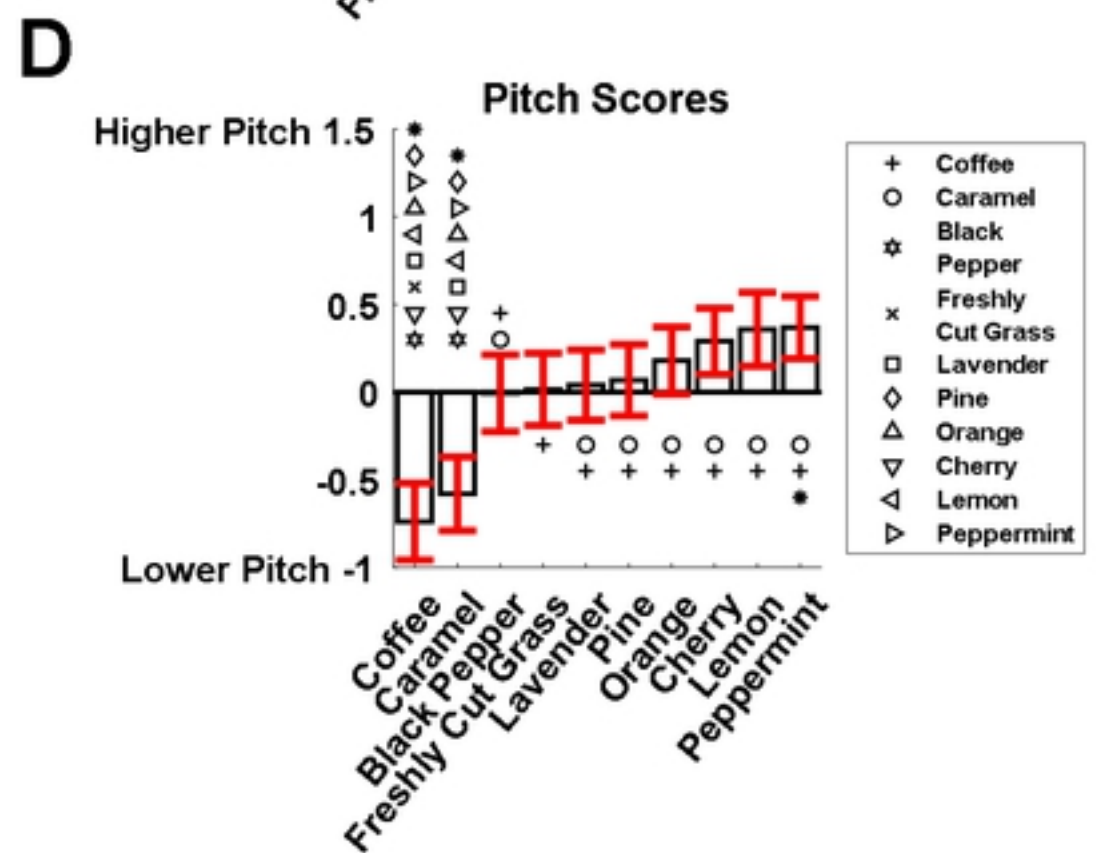
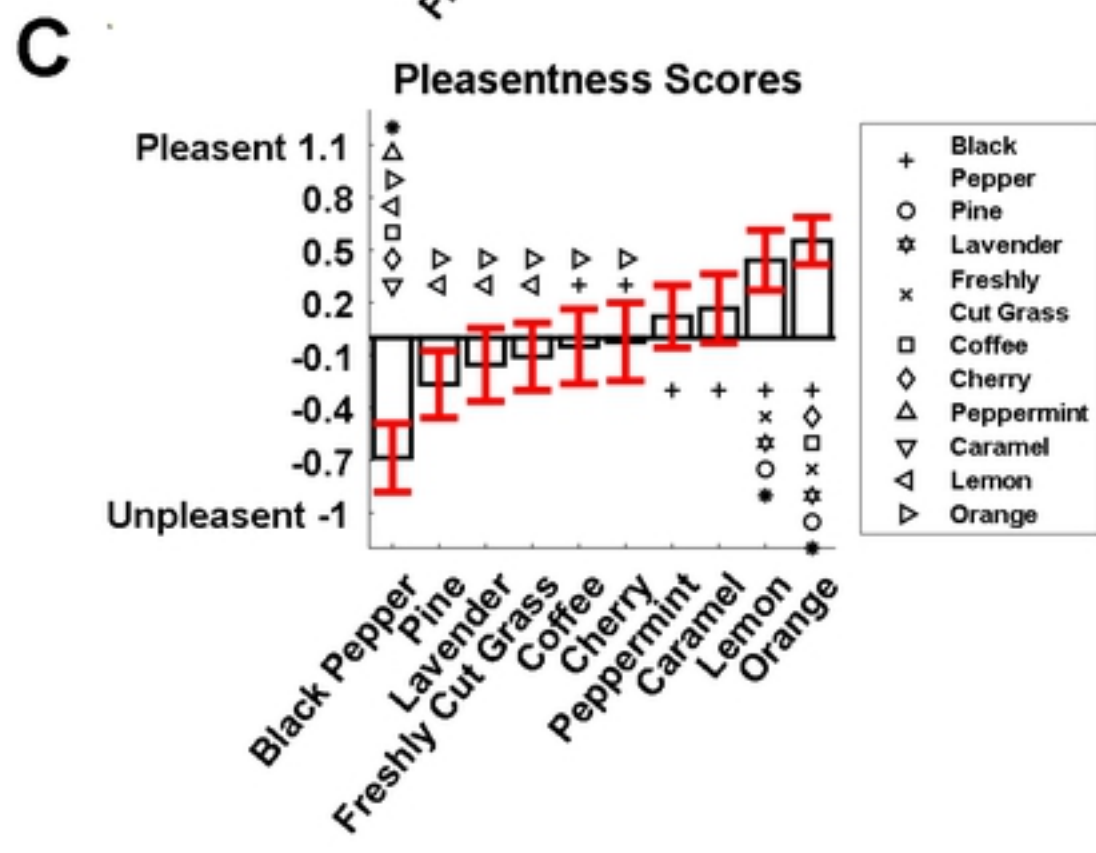
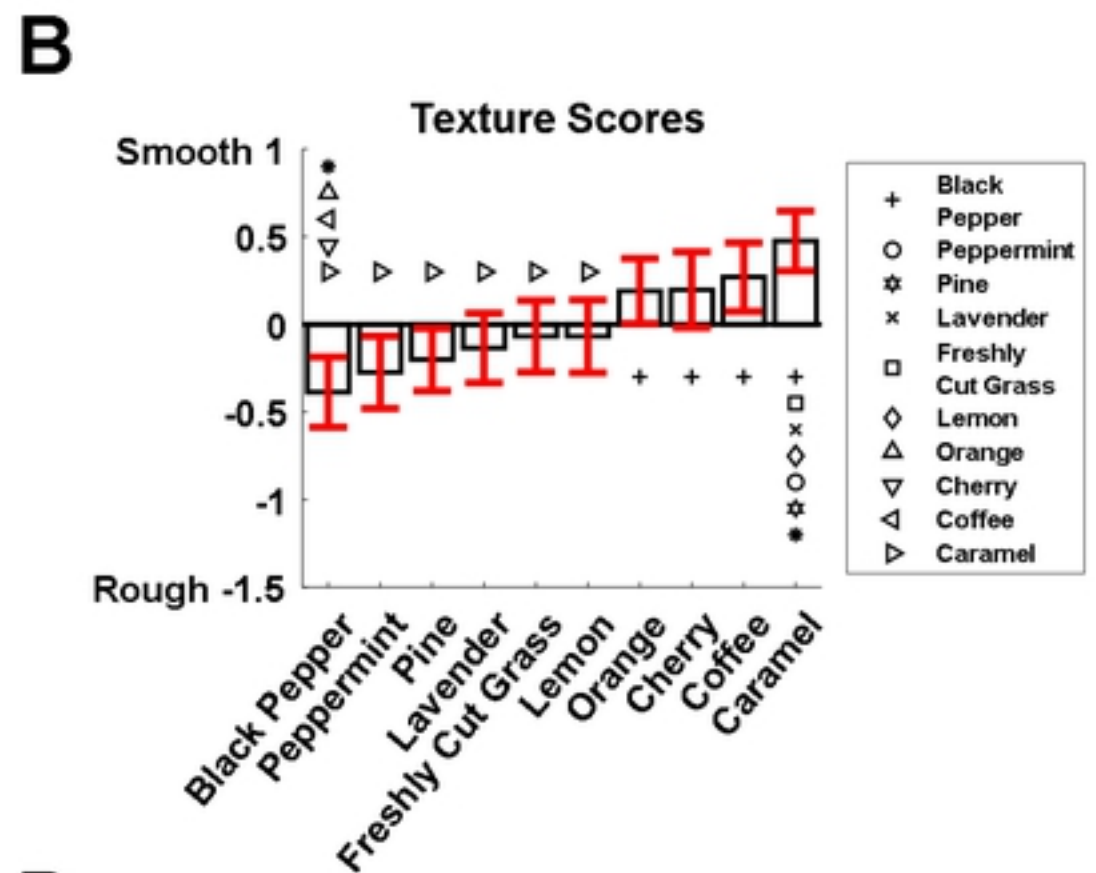
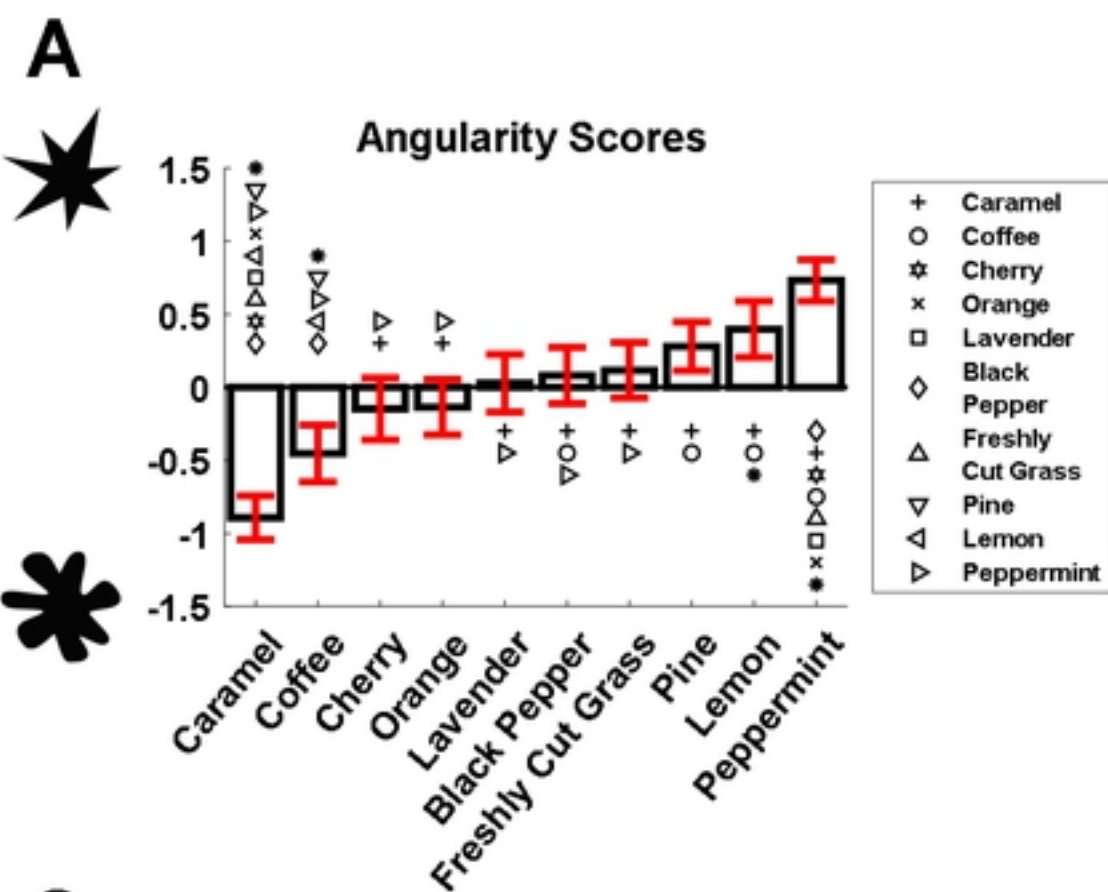


Figure 1

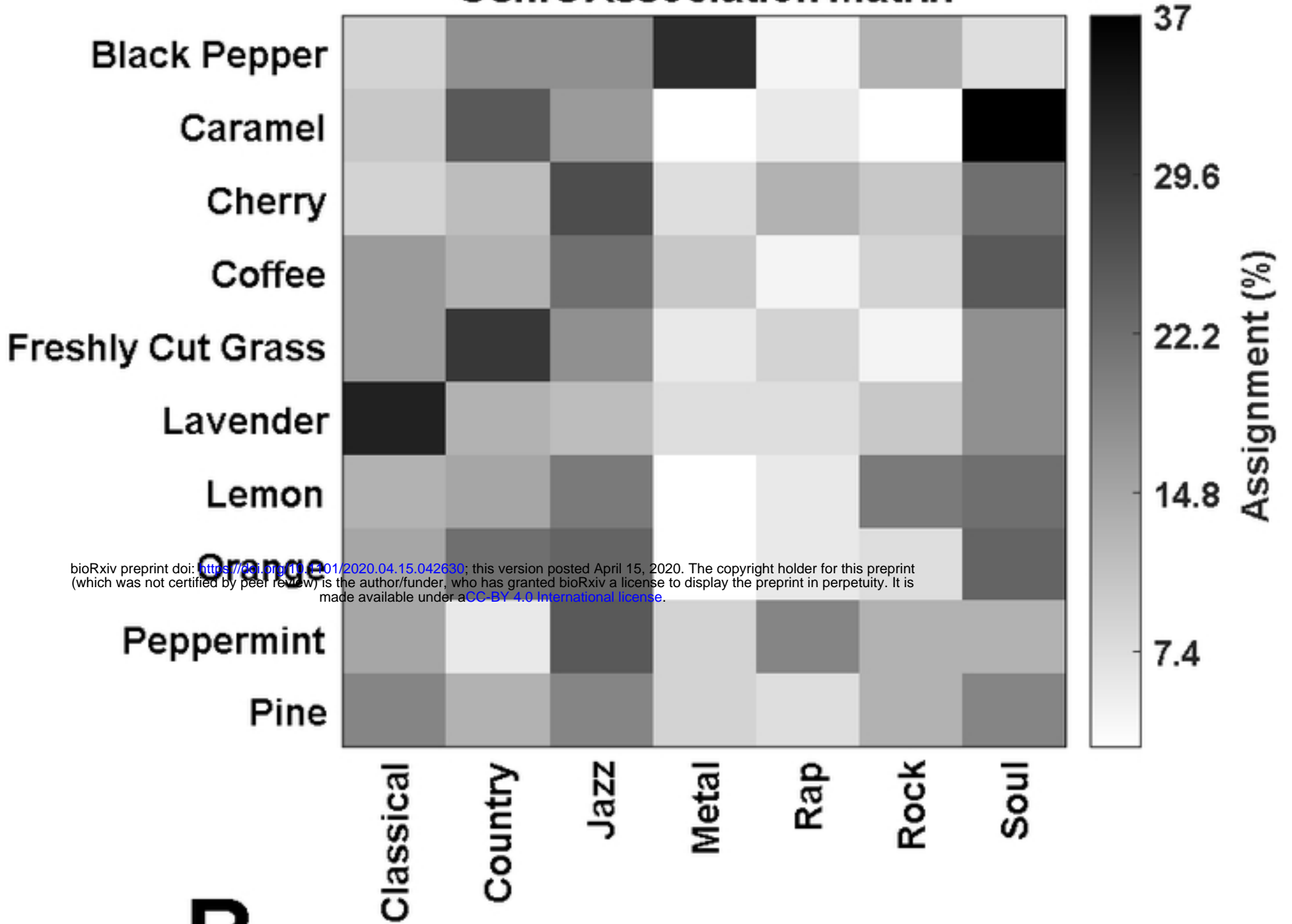
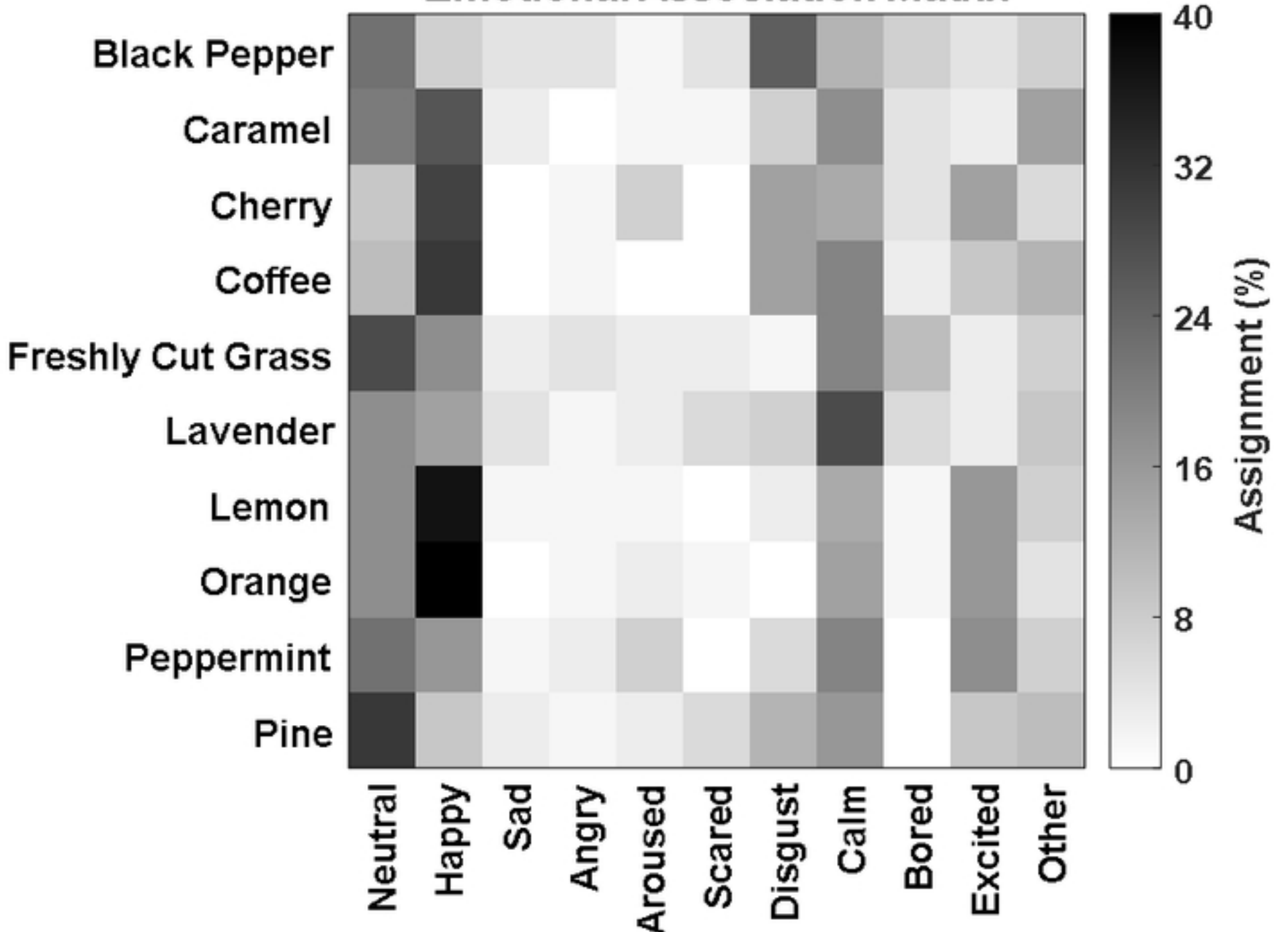
A**Genre Association Matrix****B****Emotional Association Matrix**

Figure 2

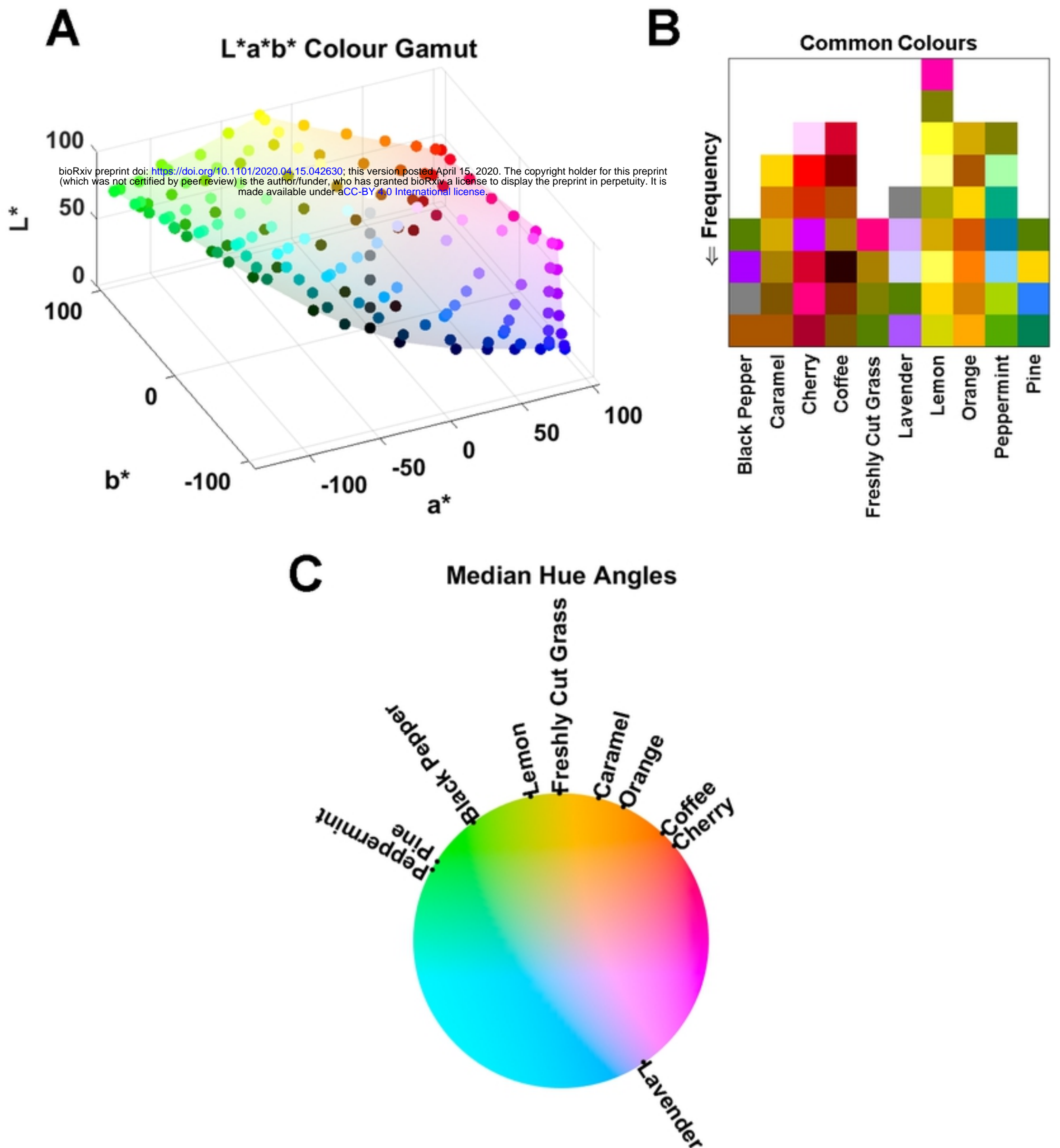


Figure 3

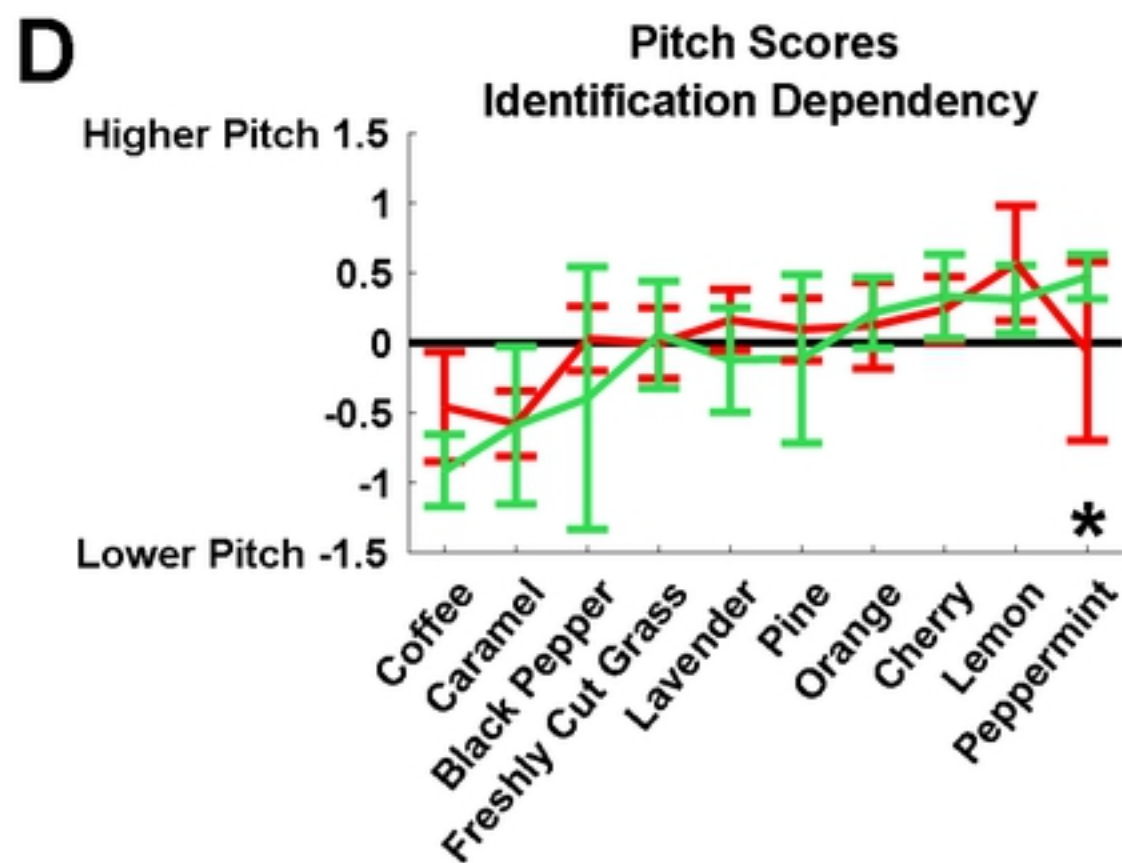
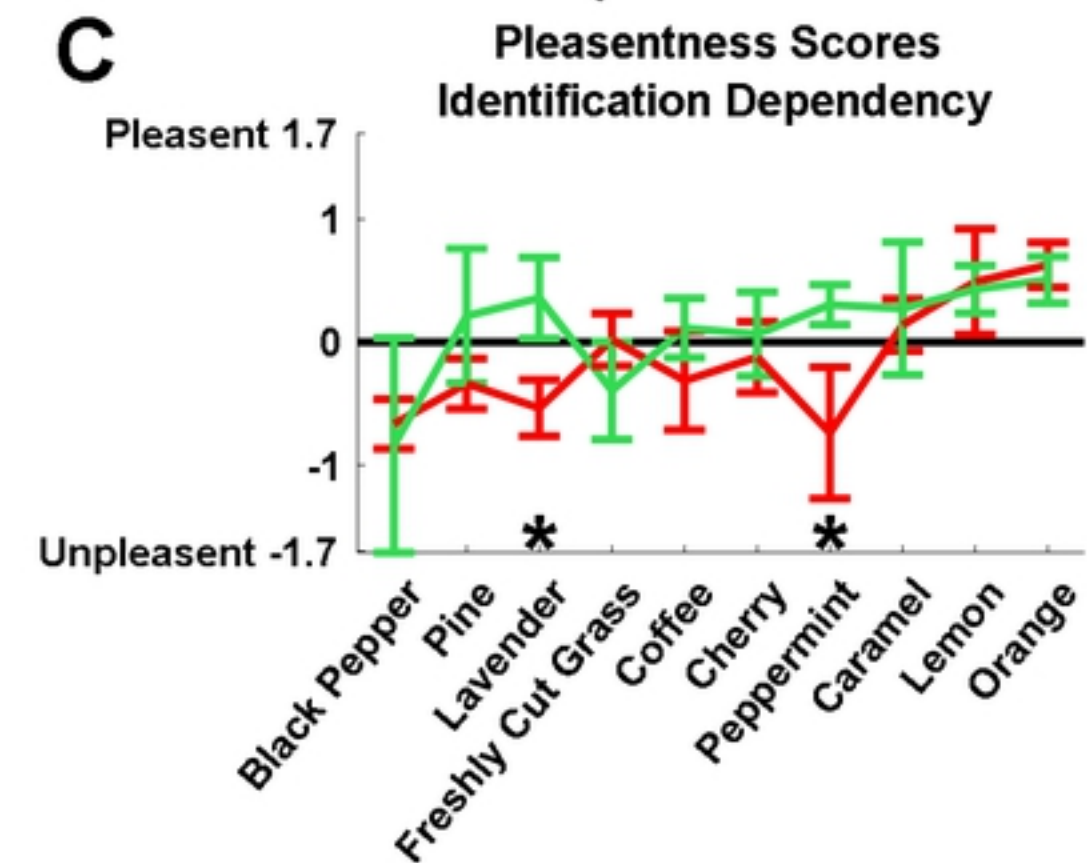
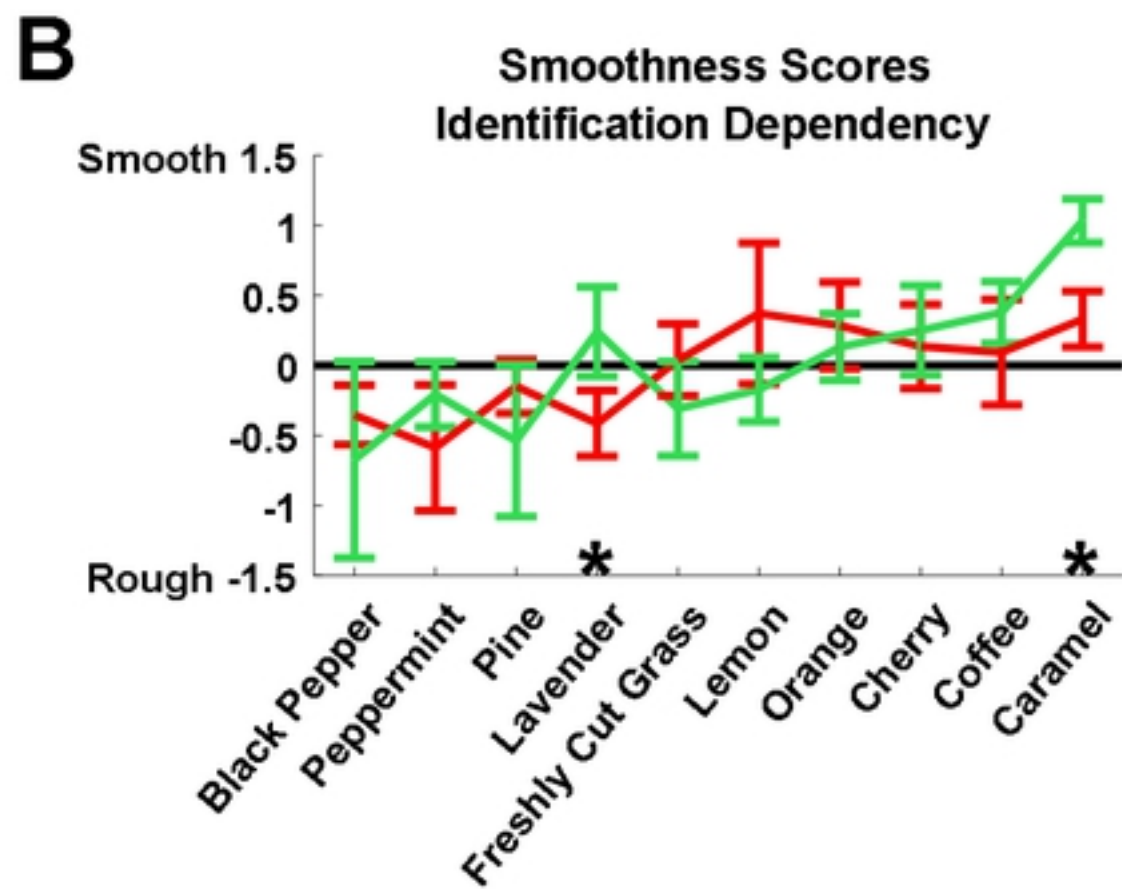
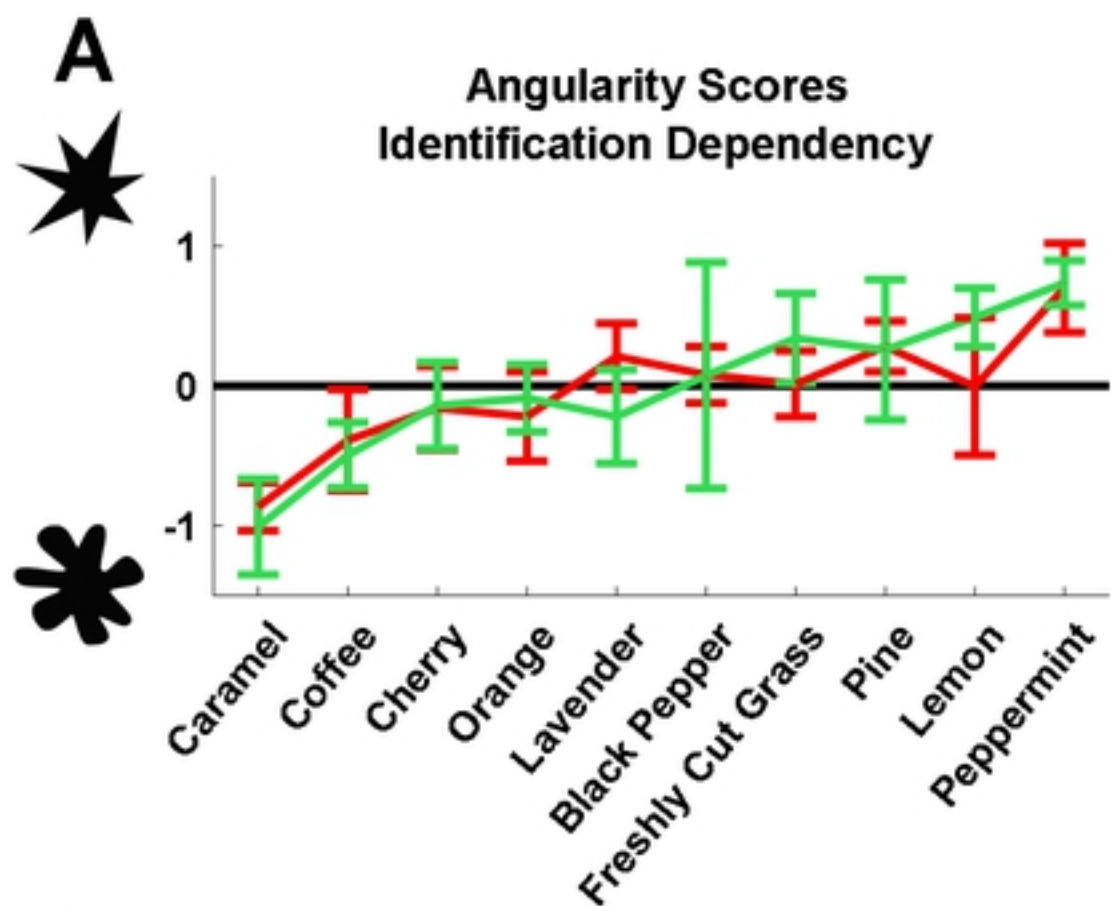


Figure 4

Common Colours For Misclassified Odours

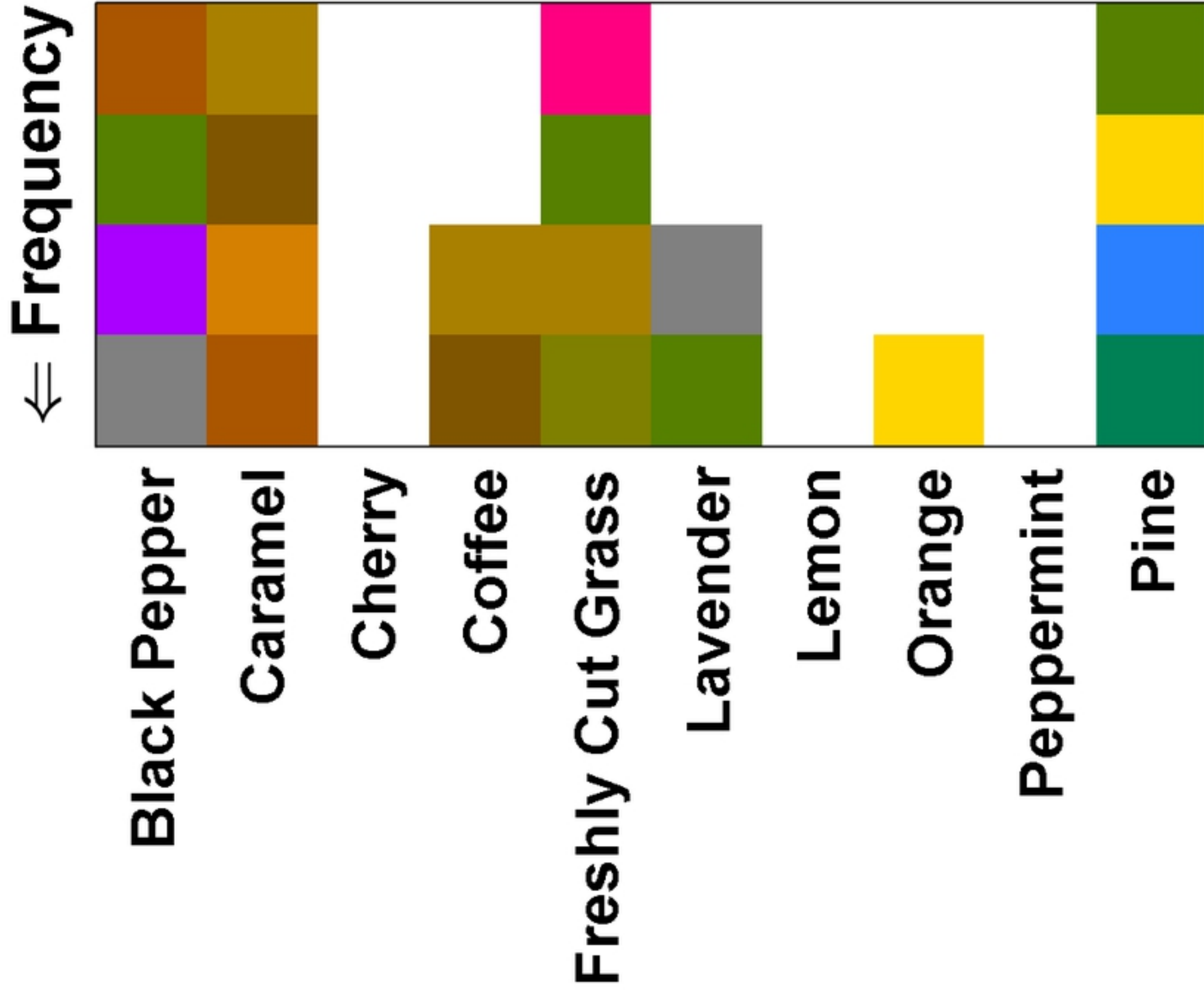


Figure 6

Presented Stimuli

Identification Association Matrix

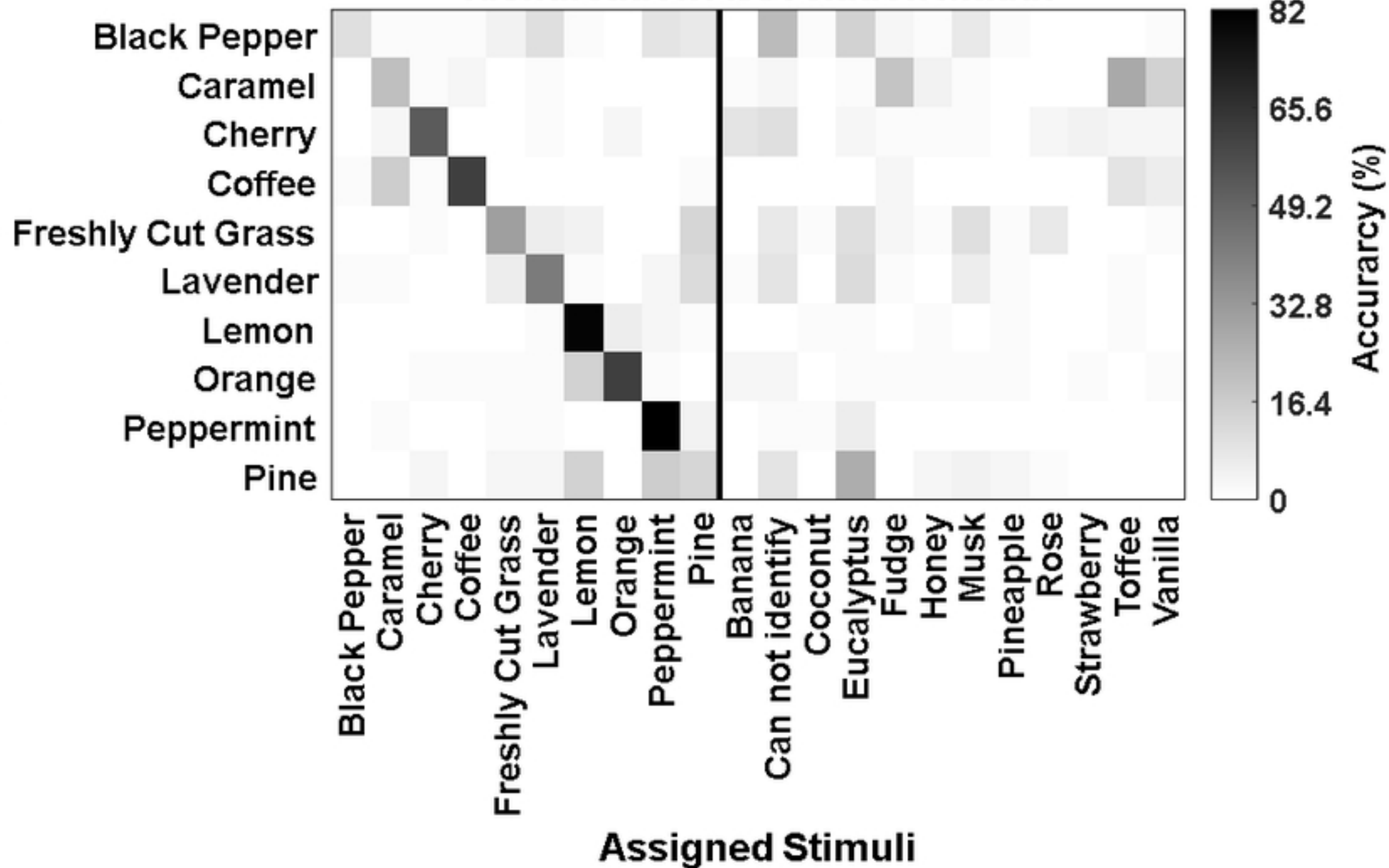


Figure 7

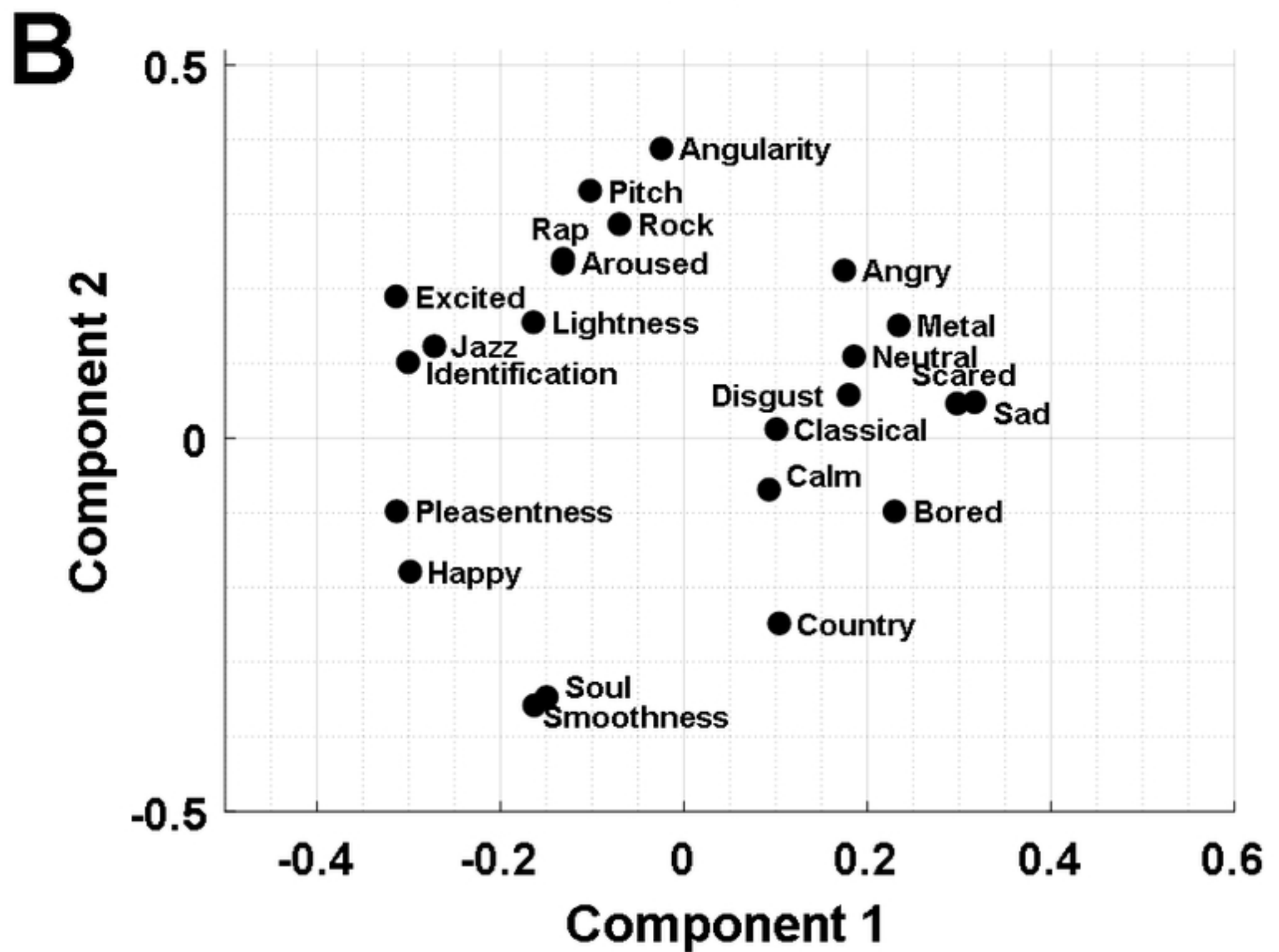
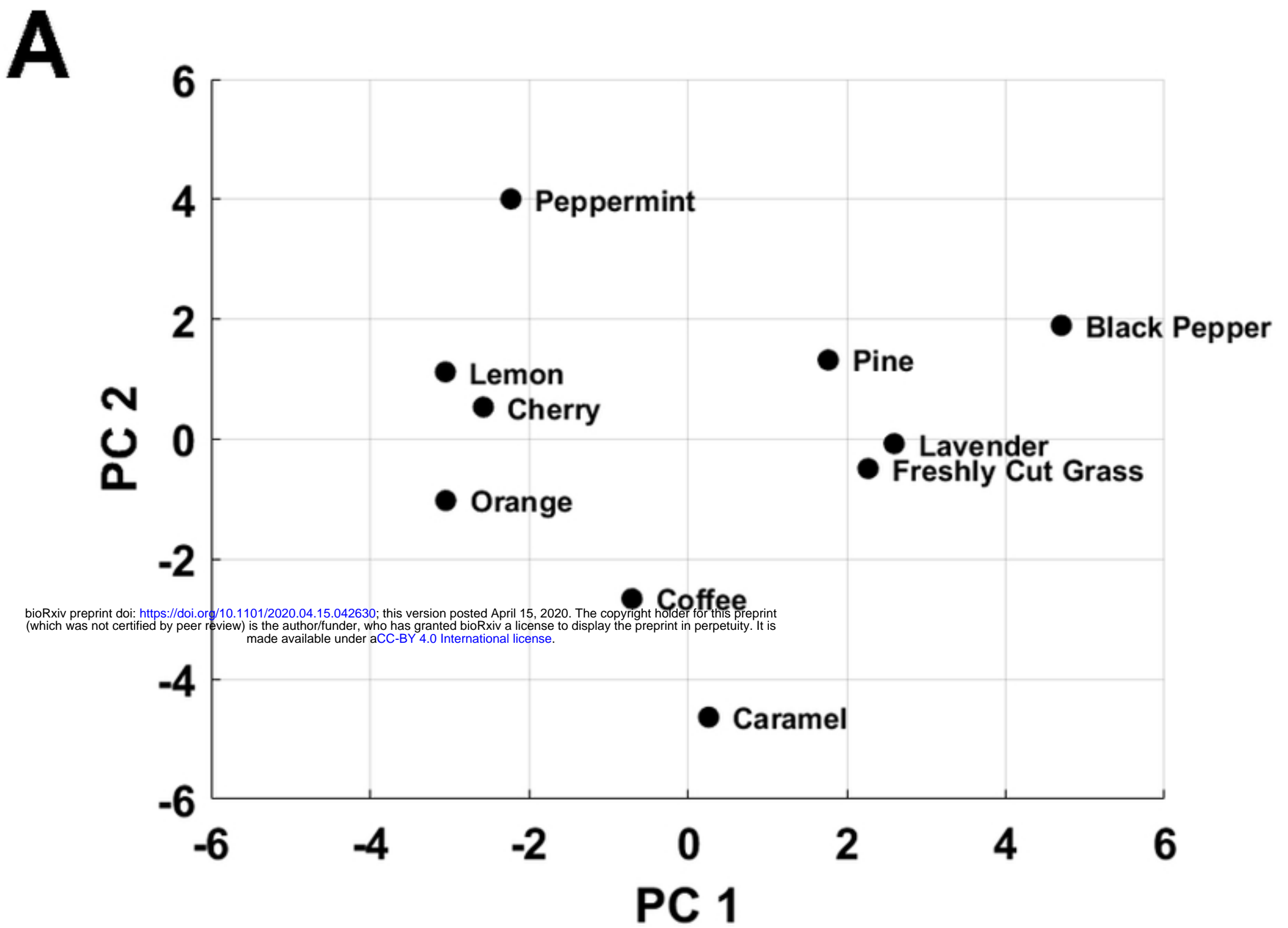
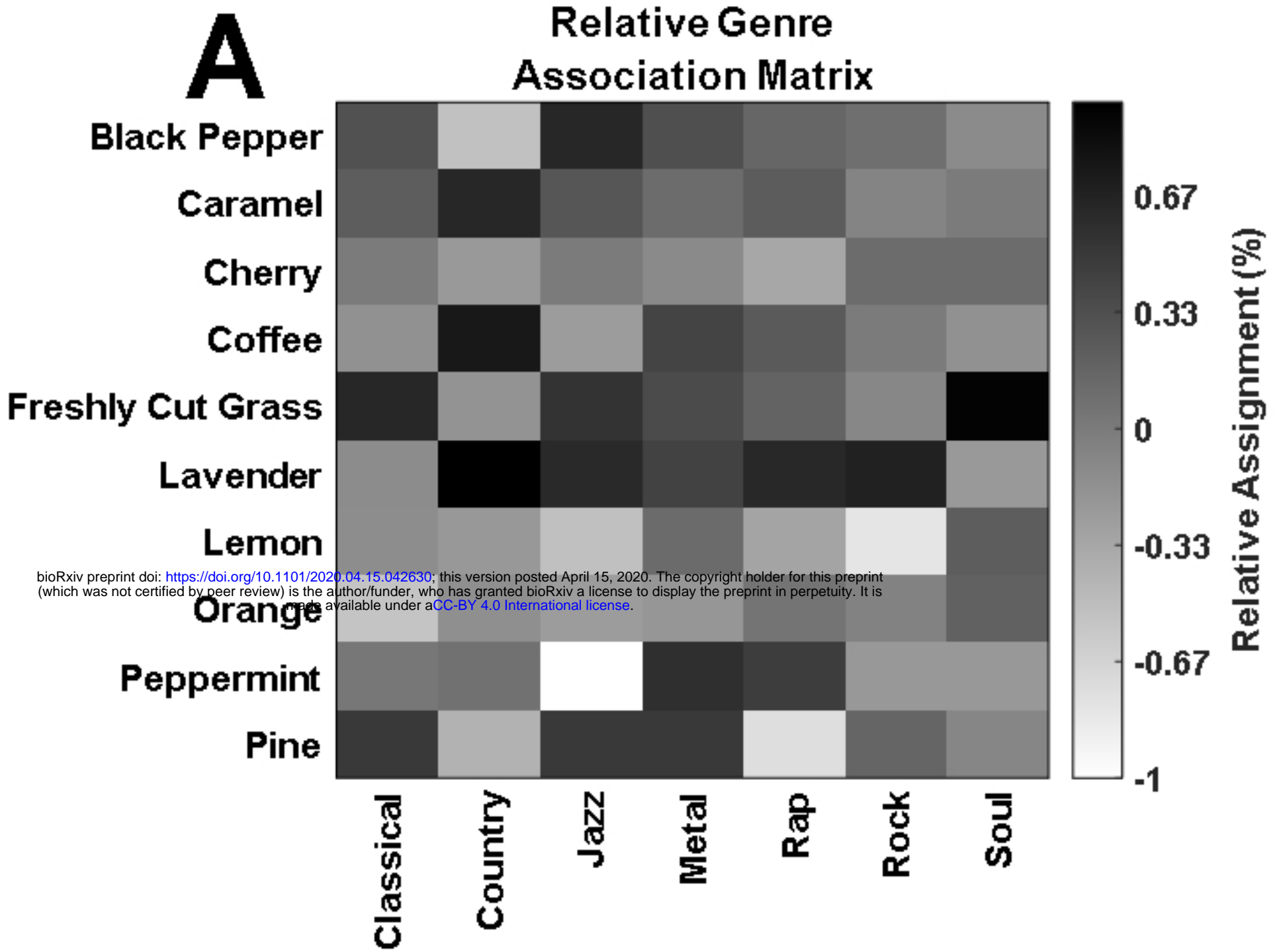


Figure 8

Relative Genre Association Matrix



Relative Emotional Association Matrix

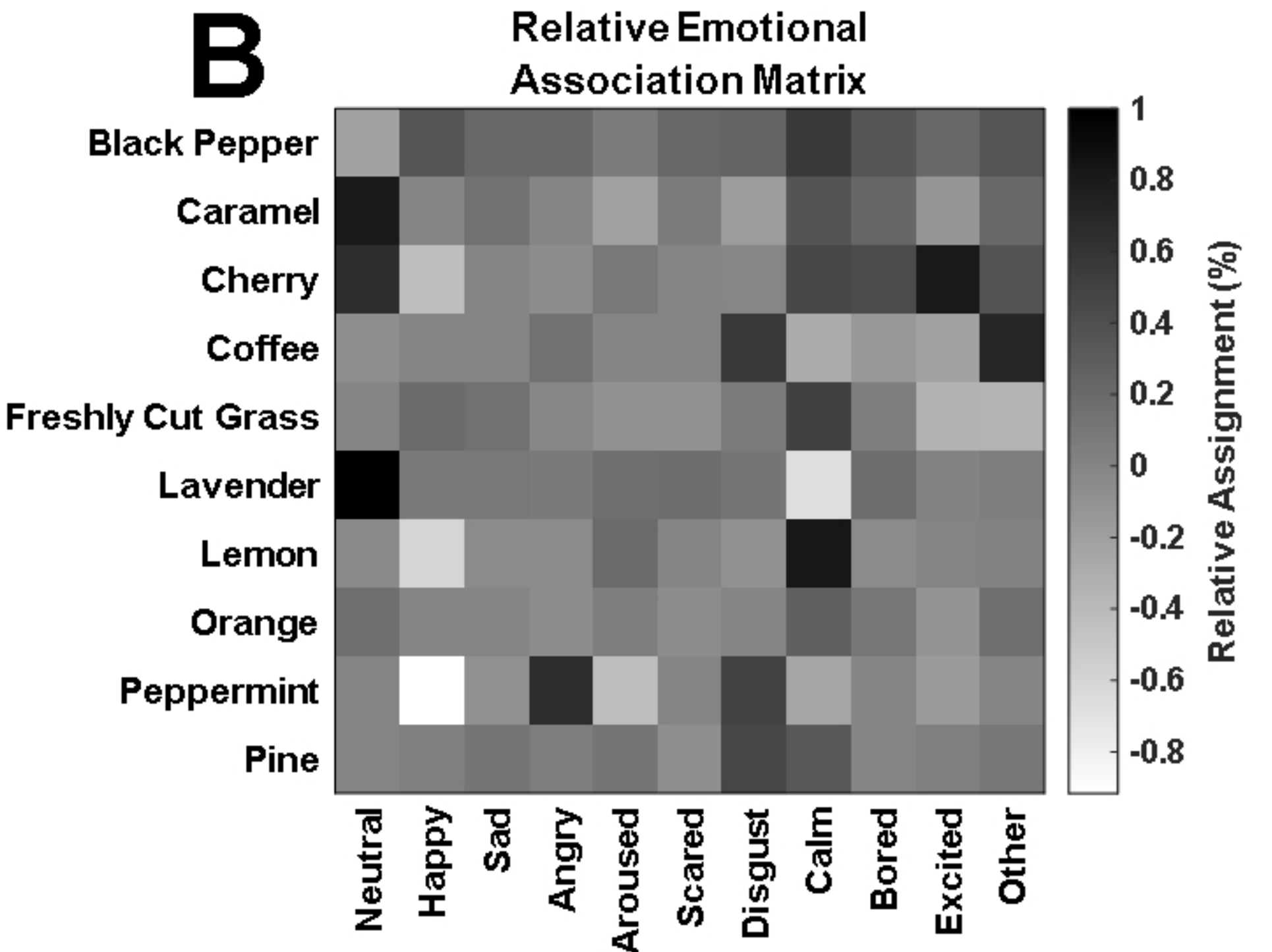


Figure 5