The Influence of Menthol-Induced Trigeminal Stimulation on Colour-Odour Matching

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Abstract

A crossmodal correspondence that has long been the interest of scientists and artists alike is that of colour perception and olfaction. Based on recent literature by Licon et al. (2018), emphasizing the role trigeminality plays in odour perception, we set out to examine the crossmodal effect of the addition of a trigeminal component (menthol) on the colour association of an odour (PEA) in a colour-odour matching paradigm. Subsequently, the colour responses and rationale of 23 participants were collected and analysed. While circular analysis of the colour hues indicated non-random choices in the menthol-only conditions, the PEA conditions and most of the mixes were randomly distributed across hues, indicating non-unanimous colour associations. The addition of Menthol to PEA seemed to cause more unanimity in colour responses, yet this was not verified statistically. Consistent with previous research, significant correlations were found between lightness and the odour ratings of irritancy ($r(229) = -0.14$, $p < 0.01$), intensity ($r(229) = -0.23$, $p = 0.03$) and a positive relationship with that of pleasantness ($r(229)) = 0.27$, $p < 0.01$). No conclusions concerning dimensional relations could be drawn between the colour saturation and odour ratings. Consistent with our hypothesis, our findings suggest a crossmodal interference stemming from the trigeminal component on participants' colour choices. However, the unexpectedly low unanimity in participants' colour responses prevents us from making substantial claims on the nature of the trigeminal involvement. By exploring the impact of trigeminality on odour-colour associations and the relationship between mixed odours and colour associations, this study deepens our understanding of how vision and smell interact as sensory modalities.

Keywords: Odour, Odour-colour associations, Crossmodal associations, Trigeminal system, odour-mixtures

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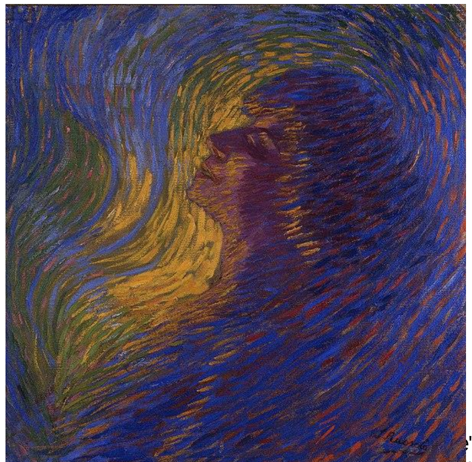
Introduction

Interest in the colour-odour synesthetic connection can be dated as far back as the Italian Futurism of the early 20th century. This is exemplified by works such as *Perfumo* by Luigi Rossolo (**Figure 1**) which portrays a fragrance wafting through the air as a swirl of colour enveloping the subject's face. The past two decades have seen a steady increase in scientific interest in such multi-sensory phenomena. Originally studied in terms of synaesthesia, a rare phenomenon where stimulation of one sensory pathway leads to involuntary experiences in another, the scientific focus has expanded to include sensory associations innate to the general population also known as **crossmodal associations.** Analogously, there have also been numerous studies that found consistent colour-odour mappings in non-synesthetes (Spence, 2020), helping us better understand the workings of both sensory modalities and their interplay in creating a unified perception of our surroundings.



"), divisionist painting by Italian Futurist artist Luigi Russolo (1885 - 1947); dated 1910.

In science, Kemp & Gilbert (1997) were one of the first to conduct a large-scale odour-colour-matching experiment; a simple setup in which participants were asked to match an odour sample with a colour chip from the *Munsell Book of Colours*. While the strength of the association varied per odour, their findings suggested consistent mappings between odours and colours. Prior research had performed similar tasks in which participants had matched odours to greyscales (Hornbostel, 1931), and clothing swatches (Fiore, 1993) or had given an imagined response to a written list of odours (Déribéré, 1978). In these studies, robust colour associations had been found with single-molecule odours, essential oils and even fragrances. As of now, over 20 published peer-reviewed studies have looked at these consistent associations and their possible origins (Spence, 2020).

Generally, it was found that colour associations arise from the direct relation to a common source object. Simply said, we associate the smell of lemon with the colour yellow because lemons are known to be yellow. This object-based explanation is further supported by the fact that the more accurate people are at identifying an odourant, the more accurate their colour matches tend to be. For example, in the experiment of Goubet et al. (2018), if the smell of a lemon was misidentified as a lime, the corresponding colour choice tended to be green instead of yellow. Coincidentally, consistent mappings have also been found in the absence of a common source object (Spence, 2020).

Prior research suggests a series of different alternative explanations to understand the nature of these sourceless colour-odour associations. The first is a theory that the associations are simply the product of the co-occurrence of two otherwise unrelated stimuli in the environment, otherwise known as **the statistics of the environment**. As theorized by Spence, (2020), it might be that we associate sweet fruity smells with vibrant colours such as pink and green due to the packaging of candy and soft drinks. Another perspective, known as the **lexical account**, states that crossmodal correspondences of sensory qualities manifest due to common lexical terms used to describe different sensory experiences. A prominent example is the linguistic "Kiki-Bouba" effect, proving an implicit connection between "sharp" and "round" object shapes and speech sounds (Köhler, 1929). Interestingly, this effect translates to other senses as well, with angular shapes often being matched with pungent smells (Metatla et al., 2019). Others propose the association between sensory qualities is mediated through **hedonics** and/or **emotions:** certain stimuli may be perceived as belonging together because they match in valence or emotion (Schifferstein & Tanudjaja, 2004). Lastly, one gets the theory of a **shared neural representation** which states that there is an overlap in brain functionality behind the processing of sensory input from different senses. For example, Hornbostel, (1931) found that participants were able to sort single molecule odours based on "smell brightness" by coupling them to different shades of grey. The study by Kemp & Gilbert (1997), mentioned earlier, also discovered an inverse relationship between odour strength/intensity and lightness, whereby stronger odours coincided with darker colours. Similar dimensional relationships were found in Stevenson et al. (2012) and Tamura & Okamoto (2023). Instead of considering these explanations to be entirely separate, the prevailing notion in literature remains that varying combinations of these explanations, instead of a single one is most suitable when trying to understand odour-colour associations in practice.

To explore the relationship between these accounts, Stevenson et al. (2012) studied how different semantic (familiarity, nameability) and perceptual (intensity, irritancy, and hedonics) odour ratings from participants relate to the colour association. In essence, they found that less familiar odours correlated primarily to the perceptual factors of intensity, irritancy and hedonics. Irritating, intense odours were judged to be darker, while more pleasant odours were rated as lighter. More recently Tamura & Okamoto (2023) further confirmed this inverse relationship between odour intensity and colour lightness and the positive correlation between pleasantness and colour lightness. Moreover, they theorized that the ability of some of the odourants to stimulate the trigeminal nerve might have accentuated the apparent correlation between intensity and colour lightness. These findings shed light on the yet unknown relationships between certain perceptual odour characteristics such as trigeminality and colour matches.

For further context, the chemical activation of the trigeminal nerve often leads to sensations like stinging, tingling, irritation, or thermal sensations. For instance, eating hot peppers containing capsaicin can cause a burning sensation, while the smell of menthol in toothpaste can elicit a cooling feeling (Cayeux et al., 2023). A study by Licon et al. (2018) demonstrated that these trigeminal sensations play a bigger role in the categorization of odour than previously thought. In an experiment, participants evaluated odours for semantic and perceptual traits. Through *principle component analysis* (PCA) researchers identified dominant traits in both perceptual (pleasantness, edibility, familiarity, intensity) and trigeminal (irritation, pain, coolness, warmth) spaces. Irritation, coolness, and pain emerged as key dimensions, indicating a significant role for trigeminal characteristics in our categorisation of odours.

While the significance of trigeminal components in odour perception is evident from previous research (Licon et al., 2018), to date no study has looked specifically at trigeminal interaction in a colour-odour matching paradigm. Besides, past matching paradigms employed limited odour manipulation configurations, with the majority of setups primarily focusing on essential oils or single molecule odours with at most three dilutions (Spence, 2020). Hence, we aim to investigate the crossmodal effect of a trigeminal component on colour choice in a colour-odour matching task. We hypothesize that introducing a trigeminal component to odours will induce crossmodal interference in participants' colour associations. Specifically, we anticipate observing a systematic alteration in colour choices following the addition of trigeminal stimuli, although the precise nature of this shift remains uncertain. Additionally, we predict that stimuli containing trigeminal components will exhibit a stronger association with perceived irritancy ratings (Filiou et al., 2015).

In the current setup two odour compounds were chosen based on similar expected recognizability and use in previous olfactory research as mixtures (Filiou et al., 2015); menthol as a trigeminal component and phenethyl alcohol (PEA) as odour. Three dilutions were created for each compound (low, medium, and high). To examine combinations, we paired each level of one compound with the medium level of the other (**Table 1**). In a colour-odour matching paradigm, participants were required to pick a corresponding colour for each stimulus. Colour responses were picked and analysed in the Hue, Saturation, & Lightness (HSL) dimension, chosen because of its simplicity and ubiquity in human-computer interaction. In addition to colour responses, participants gave odour ratings regarding the intensity, irritancy, and pleasantness of each stimulus. In alignment with previous studies, we expect consistent mappings between odours and hues, based on the reported colours associated with odour stimuli. Lastly, we expect to find general inverse relationships between lightness and intensity and lightness and irritancy similar to previous literature (Kemp & Gilbert, 1997; Stevenson et al., 2012; Tamura & Okamoto, 2023).

Odour groups	PEA, Menthol		
Odour levels	Low, medium, high		
Conditions	**Menthol low** (ML)	**Menthol med** (MM)	**Menthol high** (MH)
PEA low (PL)		PLMM	
PEA med (PM)	MLPM	MMPM	MHPM
PEA high (PH)		PHMM	

Table 1: Stimulus conditions and cross table. Three concentration levels for Phenyl ethyl alcohol (PEA), l-Menthol and the two combined in a cross-table setup. For the exact stimulus concentrations see **Table 7** in the appendix.

Methods

Participants

The study included a total of 23 participants, categorized by age and gender demographics as follows: 18-24 years (n = 7), 25-34 years (n = 12), and 35-44 years (n = 2); with 5 male and 19 female participants. Participants were recruited in different university buildings in Leiden and Amsterdam. Beforehand, they were screened for health risks and olfactory ability. The majority of participants (21/23) reported not having nasal congestion at the moment. Also, most participants (19/23) reported being able to breathe comfortably through both nostrils without any obstruction. Therefore no participants were excluded based on olfactory ability. Further checks were performed to check for (colour) vision-related deficiencies. In total, two male participants (age: 25-34) were excluded from any colour choice analyses based on colour vision deficiency and distorted response in the colour-picking task. Olfactory-only analysis included all participants.

Materials

Olfactory stimuli

Through preselection the following two odour components were selected: Phenyl ethyl alcohol (PEA) and (-)-Menthol. Odours were presented in amber glass bottles with a volume of 120mL and a wide opening (diameter: 58mm). Both odourants were solved in 99.5% pure propylene glycol to create a final volume of 15mL. The different odour concentrations were fine-tuned to create three distinct odour levels for both compounds that were equivalently intense over the different odour levels. The same concentration levels were used to create the mixes (see **Table 7** in the appendix). The odours were combined in a cross-table format, creating 11 odour samples in total (**Table 1**). In addition to PEA and Menthol, Isoamyl acetate (banana) was used as a test odour.

Colour presenter

The colour picker was presented on a 15.6-inch Full High Definition (FHD) LED Backlit display with a resolution of 1920 x 1080 pixels, a 16:9 ratio and a luminance of 220 nits. The colour match tool was programmed enabling users to select colours by adjusting the hue, saturation, and lightness levels on a graphical interface (**Figure 2A**) which participants could navigate using a separate mouse. The sensory task was hosted as a Flask web application using Iro.js JavaScript widget for the colour picker.

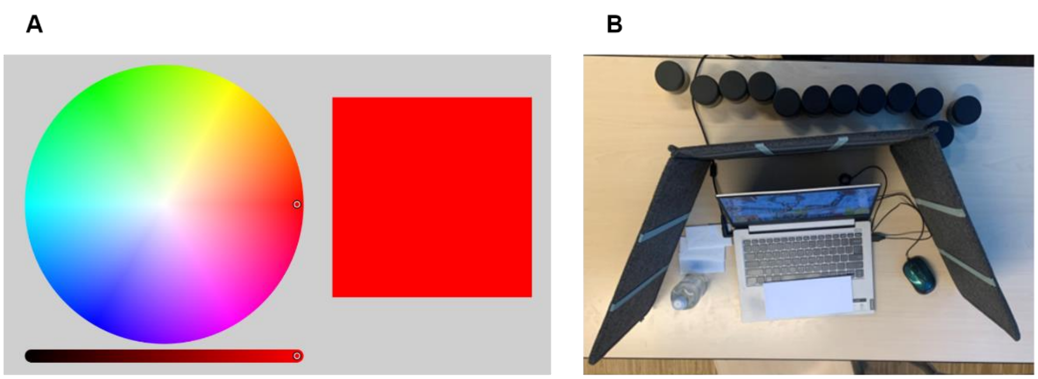


Figure 2: Experimental setup. A) HSL colour picker. Hue ranges from 0-360° around the circumference. Saturation and lightness both range from 0 -100. The colour space has the shape of a double cone. The lightness, controlled with the slider below the circle is 100% at the tip of the cone, and 0% at the bottom. The colour space resembles a double cone. Lightness is controlled with a slider below the circle, with 100% at one tip and 0% at the bottom. Saturation is represented by the radius, reaching the full range (0-100%) at 50% lightness. The panel right from the picker displays the chosen colour. **B)** The experimental setup.

Setup

Testing was done at six different locations. In each location, the setup in **Figure 2B** was used. Participants sat behind a screen with the experimenter on the opposite side of the screen handling the stimuli. Tissues and a water bottle were provided for the convenience of the participants.

Sensory evaluation

In addition to the colour-picking task, participants were required to provide a sensory evaluation of each odour stimulus. Based on previous research, the characteristics of intensity, irritability, and pleasantness were evaluated using a 7-point Likert scale. (Stevenson et al., 2012). Intensity ratings were used to assert successful odour manipulation. Irritation was measured to possibly substantiate the participant's perception of stimuli with trigeminal activity. To ensure irritation was interpreted in terms of trigeminal activation the question was formulated in the following manner: "*How irritating to your nose* *is the odour? For example, imagine the experience of smelling a sharp mustard or how the cold smell of mint could be described as irritating."*

Procedure

The experiment consisted of two rounds of smelling the same set of odours in the same sequence. Four pseudo-random orders were created to prevent any bias in the order the stimuli were presented. The first round was the colour-matching task. Participants received one of the odour samples and were allowed 5 seconds of exposure after which they had to provide a matching colour using the colour picker. Directly, after picking a colour, participants rated the confidence of their choice using a 7-point scale. The experimenter timed approximately 40 seconds in between sniffing each odour to prevent olfactory overstimulation. At all times participants were allowed to take a break if olfactory saturation occurred. In the second round participants had to provide sensory evaluations. Afterwards, participants were questioned on the odours they recognized and the tactics used for the colour-matching task. The exact questionnaires and experimental setup can be found in the appendix. Sensory evaluations were performed separately in the second round so as not to influence the colour selection process. After taking the experiment participants had the opportunity to leave additional comments.

Statistics

To assert our stimulus manipulation, we expected the intensity ratings of the odour levels within all the conditions to differ significantly. Concerning the trigeminal component, we expected a rise in perceived irritation with each incremental level of menthol concentration. Moreover, we anticipated a greater perceived irritation in the menthol condition compared to the PEA condition, and likewise, a higher perceived irritation in the PEA mix with menthol compared to only PEA. Condition comparisons were conducted using either dependent T-tests or the non-parametric Wilcoxon signed-rank test. Multiple condition comparisons were done using repeated-measures ANOVA or the non-parametric Friedman's test. The participant's colour choices were registered and analysed using the *HSL* colour space as was done in Kemp & Gilbert (1997). Hue, being circular data, was analysed using the *CircStat* circular statistics toolbox in MATLAB (Berens, 2009).

Colour choices were studied in the HSL colour dimensions. The unanimity of the colour choice per condition was studied as the circular distribution of the hue values of the colour choices per condition. Per condition, the resultant length ($\bar{R}$), a value between 0-1 indicative of the spread around the hue circle, was calculated. The higher the value of $\bar{R}$ the more concentrated the data is around a certain hue value, and the more unanimous the colour choice of that condition. To further test if the distribution of hue-values significantly deviated from a uniformly spaced distribution of hue-values Rayleigh's test for circular uniformity was used. Among the assumptions of this test is that the data distribution does not significantly deviate from the von Mises distribution, a circular variant of the normal distribution. The risk of performing the test with a non-von Mises distribution is wrongly classifying a multimodal distribution as uniform. We are predominantly interested in a departure from uniformity towards an unimodal colour choice per condition, therefore we will limit our tests for uniformity to that of Raleigh's. Dimensions of saturation and lightness were evaluated as possible correlates of the sensory evaluations through a Pearson's correlation or the non-parametric Spearman's rank-order correlation.

In addition to comparing the HSL values between participants between conditions, we also looked at the shift within participants between the single and mixed runs.

Furthermore, we compared the distances between the conditions within participants through the CIE Lab colour space a more perceptually uniform alternative to other digital colour spaces.

Lastly, we looked at the confidence scores and the open-ended questions. The former was looked at to gauge the general confidence participants had in selecting colours for the odours and if there might be differences between the odour groups or between the singles and mixes. The idea is that participants are more confident in selecting colours for recognizable odours or simpler odours (singles). Open-ended questions by participants were analysed for correctly identifying the odour components, the tactic used for picking a colour and an assessment of the underlying mechanism used for the colour association (perceptual, associative, or hedonic).

Results

Irritancy

Sphericity was maintained for Menthol Irritancy across odour levels ($\chi^2 = 0.75$, $p = .69$), however, tests for normality showed that ML, MM, and MH followed non-normal distributions ($p < 0.05$). Results of the Friedman test indicated a significant difference in irritancy levels among the conditions ($\chi^2(2) = 9.87$, $p < 0.01$). Contrarily, the Nemenyi post hoc test did not report any significant differences ($p > 0.05$). The Wilcoxon signed-rank test on PEA vs Menthol indicated no significant difference between the irritancy levels of these two odour groups (W = 716.5, $p = 0.82$, *two-sided*). In comparing irritancy between PEA and the PEA mix using the Wilcoxon signed-rank test, also no significant difference was found (W = 426.5, $p = 0.75$, *two-sided*).

Intensity

We compared intensity ratings within participants to evaluate the success of manipulating three odour levels in each group. Within the PEA condition, none of the odour levels assumed normality ($p < .05$), but the groups did meet the assumption of sphericity ($\chi^2(2) = 1.13$, $p = 0.57$). The Friedman test, used to assess differences among the conditions, yielded a non-significant result, suggesting no significant variation in intensity scores across the three odour levels ($\chi^2(2) = 2.03$, $p = 0.36$). Similar to PEA, none of the odour levels within the Menthol condition proved normally distributed ($p < 0.05$), yet again the assumption of sphericity was met ($\chi^2(2) = 0.83$, $p = 0.66$). The Friedman test revealed a significant difference in intensity ratings across the three levels ($\chi^2(2) = 10.7$, $p < 0.01$). The Nemenyi Post-hoc indicated a significant difference between ML (median = 4.0, IQR = 2.0) and MH (median = 5.0, IQR = 1.0), while no significant differences were observed between MM (median: 4.0, IQR: 2.0) and ML ($p > 0.05$), or between MH and MM ($p > 0.05$). In the PEA mix condition, PHMM and PLMM were non-normal ($p < 0.05$). While MMPM and the rest of the menthol mix conditions were tested normal ($p > 0.05$). Both PEA mix and Menthol mix intensities demonstrated sphericity, as indicated by Mauchly's tests (PEA mix: $\chi^2(2) = 1.75$, $p = 0.42$; Menthol mix: $\chi^2(2) = 0.02$, $p = 0.99$). The Friedman test did not reveal a significant difference in intensity ratings ($\chi^2(2) = 3.69$, $p = 0.16$) between the three PEA mix conditions. Similarly, the repeated measures ANOVA also did not reveal a significant difference in intensity ratings (F(2, 44) = 0.05, $p = 0.95$) across the three levels of the menthol mix. The odour levels across conditions were also compared to account for the equality of odour strength between conditions. The Friedman test indicated no significant differences in intensity rating between the odour groups for low ($\chi^2(3) = 6.30$, $p = 0.01$), medium ($\chi^2(2) = 0.03$, $p = 0.99$) or high ($\chi^2(3) = 7.06$, $p = 0.07$).

Colour Choices

An overview of the colour responses per condition can be found in **Figure 3**. As mentioned earlier, two participants were excluded from further colour analysis. The first is due to colour blindness, and the second is due to monotonous colour responses within a specific hue range (dark muddied brown). Hue results are plotted on half of a polar axis (180° to 0°) seen in **Figure 4** and described in **Table 3**.

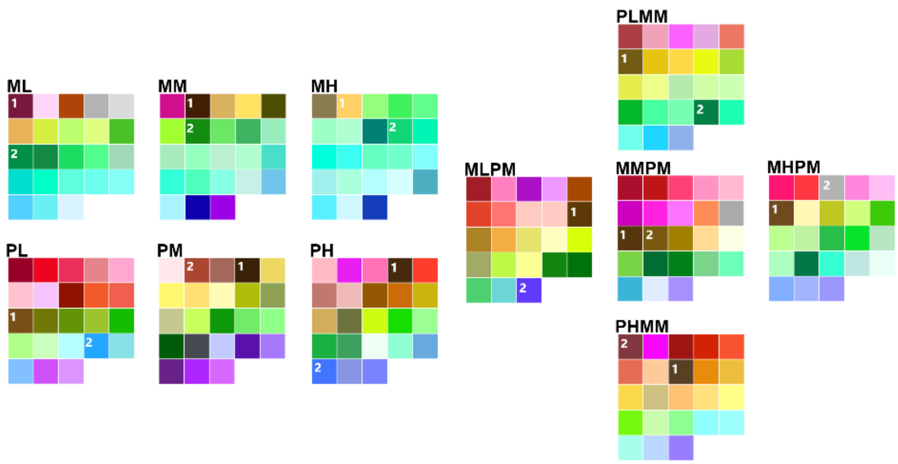
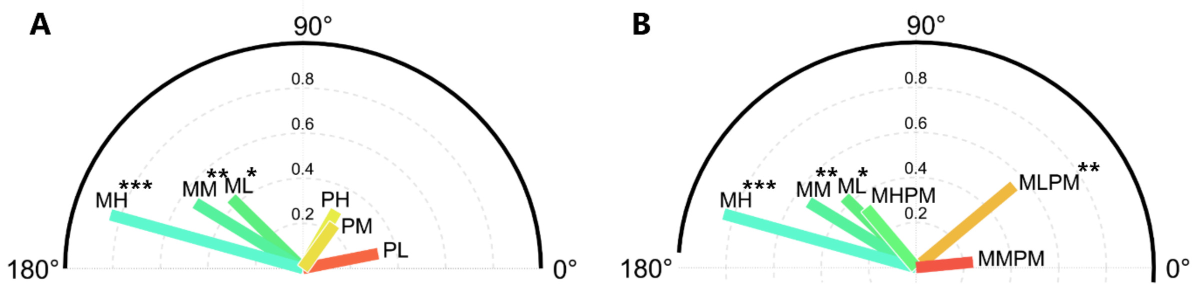


Figure 3: Colour choices grouped per condition. Colour panels are grouped into categories based on 12 hue intervals and sorted first from dark to light, then from most to least saturated. Hue intervals: red-violet (316°-345°), red-orange (346°-15°), yellow-orange (16° - 45°), yellow (46°-75°), yellow-green (76°-105°), green (106°-135°), blue-green (136°-165°), cyan (166°-195°), blue (196°-225°), blue-violet (226°-255°), violet (256°-285°), magenta (286°-315°). **1:** Participants excluded based on skewed colour choices. **2**: Participants excluded based on colour blindness.

The resultant length $\bar{R}$ of each condition is given as a rod pointing towards the mean hue angle of that condition. The length of the rod represents $\bar{R}$ (concentration of the values around the circle). Circular variance V, defined as $1 - \bar{R}$ and represents the circular spread. The colour of the rod's surface is the colour mean, calculated by taking the mean saturation, mean lightness, and $\bar{\theta}$. Rayleigh's test for non-uniformity tested significant for ML ($p = 0.02$), MM ($p < 0.01$), MH ($p < 0.001$), MLPM ($p < 0.01$) and PHMM ($p = 0.01$), indicating unimodal distribution concentrated around a certain hue value. The MH condition ($\bar{\theta} = 163.3$, $\bar{R} = 0.84$) possessed the strongest concentration of hue values, falling into the colour range of cyan (151° – 210°). ML ($\bar{\theta} = 134.01$, $\bar{R} = 0.43$) and MM ($\bar{\theta} = 147.29$, $\bar{R} = 0.54$) means are shifted slightly clockwise into green hue ranges (91° – 150°). The remaining two non-uniformly distributed conditions MLPM ($\bar{\theta} = 41.37$, $\bar{R} = 0.55$) and PHMM ($\bar{\theta} = 51.47$, $\bar{R} = 0.45$), had the mean hues of orange/yellow (41° - 50°).

Comparing ML to MLPM a clockwise shift of approximately 90° from the colour range of the menthol conditions to that of the PEA and PEA mixed can be seen. $\bar{R}$ of each condition is shown in **Table 2**. The difference scores of the $\bar{R}$ after the addition of MM or PM can be seen in **Table 3**.



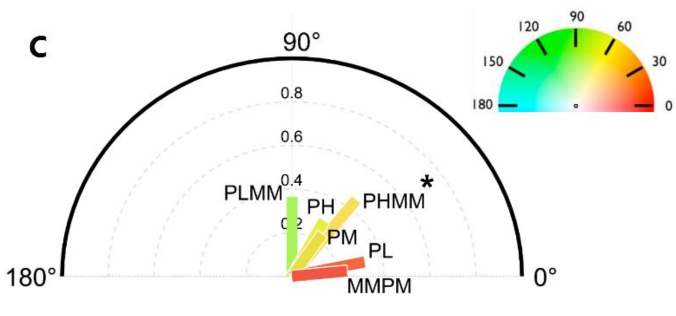


Figure 4: Polar plots of the conditions. Resultant length $\bar{\boldsymbol{R}}$ is given as a rod pointing towards the mean angle $\bar{\boldsymbol{\theta}}$. Colour of the rods is mean colour per condition (H = $\bar{\theta}$, S = $\mu_{saturation}$, L = $\mu_{lightness}$). **A)** Menthol low, medium and high (ML, MM, MH) and PEA low medium and high (PL, PM, PH). ML, MM, and MH all tested significantly non-uniform on Rayleigh's test (α = 0.05). **B)** Menthol single vs. menthol mixed (MLPM, MMPM, MHPM). MLPM tested significantly non-uniform with (α = 0.05) **C)** PEA single vs. PEA mixed (PLMM, MMPM, MHPM) PHMM tested significantly non-uniform ($\boldsymbol{\alpha}$ = 0.05). ***p** < .05, ** *p* < .01 and *****p** < .001.

Conditions	$\Delta\bar{\boldsymbol{R}}$
PLMM - PL	0.04
MMPM - PM	0.01
PHMM - PH	0.16
MLPM - ML	0.12
MMPM - MM	-0.30
MHPM - MM	-0.51

Table 3 Differences in circular concentration: Differences in $\bar{R}$ calculated by subtracting the single odour condition from the mixed odour condition.

Conditions	$\bar{\boldsymbol{\theta}}$	$\bar{\boldsymbol{R}}$	$\boldsymbol{S}$	$\boldsymbol{p}$
PL	11.75	0.32	0.68	0.11
PM	55.7	0.23	0.77	0.32
PH	61.32	0.29	0.71	0.17
ML*	134.01	0.43	0.57	0.02
MM**	147.29	0.54	0.46	< 0.01
MH***	163.63	0.84	0.16	< 0.001
PLMM	89.91	0.36	0.64	0.06
PHMM*	51.47	0.45	0.55	0.01
MLPM**	41.37	0.55	0.45	< 0.01
MMPM	5.75	0.24	0.76	0.30
MHPM	128.55	0.34	0.66	0.09

Table 2: Descriptives for the circular analysis of the hue values. For all 11 conditions the mean direction in angles $\bar{\boldsymbol{\theta}}$, the resultant length $\bar{\boldsymbol{R}}$, the circular variance $\boldsymbol{S}$, and the outcome of Rayleigh's test for uniformity (α = 0.05). *p < .05, ** *p* < .01 and *** *p* < .001.

Perceptual shifts among participants

Supplementary analyses were done that looked at the shifts within participants between the colour choices of single and mixed conditions (i.e. the shift in colour between ML and ML after the addition of PEA medium (MLPM)). Colour shifts were looked at in the HSL dimension and *CIELAB* space, with detailed results provided in the appendix (**Tables 7** & **8**)

Sensory evaluations

Firstly, sensory evaluations over the different odour levels and conditions were combined into one group and compared to the saturation and lightness respectively. The results of this analysis can be seen in **Figure 6**.

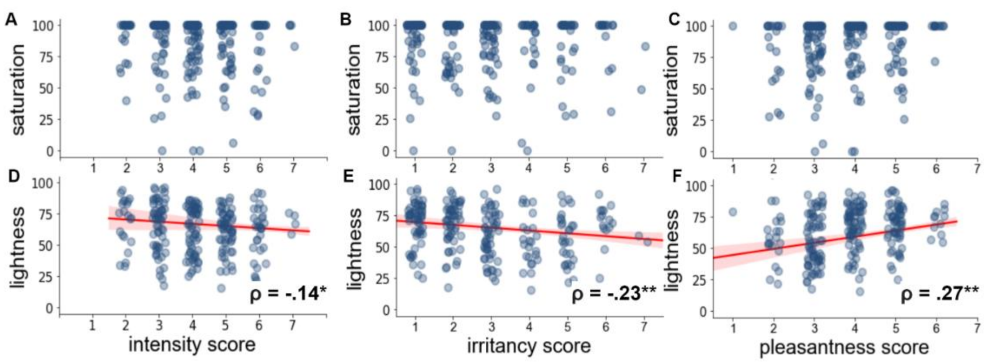


Figure 2: Correlations between the intensity, irritancy, pleasantness, and lightness and intensity. Scores of all conditions were combined. **A, B,** & **C)** Saturation (0-100%) vs intensity, irritancy, and pleasantness scores (1-7 Likert-scales) respectively. **D, E** & **F)** lightness (0-100%) vs intensity, irritancy, and pleasantness scores (1-7 Likert-scales) respectively. Spearman's rank correlation revealed negative correlations between the lightness and intensity score (r(229) = -0.14, 95% CI [-0.26, -0.02], p = 0.03) and lightness versus the rated irritancy (r(229) = -0.23, 95% CI [-0.34, -0.11], p < 0.01) with α = 0.05. Opposed to this, the pleasantness score shows a significant positive correlation with the colour lightness (r(229) = 0.27, 95% CI [0.15, 0.38], p < 0.01). See **Table 4** for the complete overview.

	r	df	CI95%	*p* -value
Intensity	-0.14*	229	[-0.26, -0.01]	0.03
Irritancy	-0.23**	229	[-0.35, -0.1]	>0.01
Pleasantness	0.27**	229	[0.15, 0.39]	>0.01

Table 4: Correlation analysis of the intensity, irritancy, pleasantness, and lightness over conditions.
*p < .05 , ** p < .01 with α = 0.05.

As is shown in **Figure 6 (A, B,** & **C)**, the saturation scores were heavily ceiled towards 100%. With more than half (58%) of the values having a saturation of 95% or higher, they were excluded from further analysis. Lightness scores, on the other hand, had a more equal distribution and could be analysed using Spearman's rank correlation after testing significantly non-normal (p < 0.05). The correlation analysis indicated a weak negative correlation with perceived intensity (r(229) = -0.14, 95% CI [-0.26, -0.02], p = 0.03) and moderate negative association with the perceived irritancy with stronger significance (r(229) = -0.23, 95% CI [-0.34, -0.11], p < 0.01). The pleasantness scores and lightness, on the other hand, demonstrated a strong positive association (r(229) = 0.27, 95% CI [0.15, 0.38], p < 0.01).

The correlations between the lightness dimension, intensity, and irritancy were further examined within the conditions (**Table 5**). It can be seen that significant correlations were observed for irritancy (r(61) = -0.29, 95% CI = [-0.51, -0.05], p = 0.02) and pleasantness (r(61) = 0.31*, 95% CI = [0.07, 0.52], p = 0.02) in the PEA conditions. However, there was no significant correlation with intensity (p > 0.05). In the menthol-only conditions, no significant associations were found between the perceptual scores and colour dimensions, including intensity, irritancy, or pleasantness (p > 0.05). On the other hand, the mixed conditions possessed the most substantial correlations. Both the PEA mixed intensity and irritancy scores displayed significant negative correlations (intensity*:* r(61) = -0.32, 95% CI [-0.53, -0.08], p = 0.01, irritancy*:* r(61) = -0.41, 95% CI [-0.15, 0.58], p < 0.01). Pleasantness again showed a significant positive correlation (r (61) = 0.38, 95% CI [0.15, 0.58], p < 0.01). The correlation results of the Menthol mixes were more or less identical, with negative slopes for intensity (r (61) = -0.27, 95% CI [-0.48, -0.02], p = 0.04) and irritancy (r (61) = -0.41, 95% CI [-0.60, -0.18], p < 0.01), and a slightly positive slope for the pleasantness score (r(61) = 0.41, 95% CI [0.18, 0.59], p = 0.56).

	rating	**r**	**df**	**CI95%**	**p**
PEA	Intensity	-0.17	61	[-0.4, 0.08]	0.17
	Irritancy	-0.29*	61	[-0.51, -0.05]	0.02
	Pleasantness	0.31*	61	[0.07, 0.52]	0.01
Menthol	Intensity	0.09	61	[-0.16, 0.33]	0.47
	Irritancy	0.11	61	[-0.14, 0.35]	0.40
	Pleasantness	0.02	61	[-0.23, 0.27]	0.88
PEA mix	Intensity	-0.32*	61	[-0.53, -0.08]	0.01
	Irritancy	-0.41**	61	[-0.6, -0.18]	<0.01
	Pleasantness	0.38**	61	[0.15, 0.58]	<0.01
Menthol mix	Intensity	-0.27*	61	[-0.48, -0.02]	0.04
	Irritancy	-0.41**	61	[-0.6, -0.18]	<0.01
	Pleasantness	0.41**	61	[0.18, 0.59]	<0.01

Table 2: Descriptives of the correlation analysis of the intensity, irritancy, and pleasantness versus the lightness per condition, *p < .05, ** p < .01 with α = 0.05.

Confidence scores

The confidence scores of the PEA and Menthol groups were compared using a two-sided Wilcoxon signed-rank test after assumptions for normality were violated (p < 0.01). Participants rated a slightly higher confidence for the colour choices of the Menthol condition (median = 5.0, IQR = 2.0) than the PEA condition (median = 4.0, IQR = 2.0; W = 211.0, p < 0.01, *two-sided*). Additionally, participants also reported being significantly less confident in their colour choice in the mixed conditions (median = 4.0, IQR = 2.0) versus the single conditions (median = 5.0, IQR = 2.0; W = 1729.0, p < 0.01, *two-sided*). Upon further inspection, no significant difference was found between PEA (median = 4.0, IQR = 2.0) and the PEA mix (median = 4.0, IQR = 2.0; W = 517.0, p = 0.33, *two-sided*).

Only Menthol tested significantly higher in confidence than its mixed counterpart (W = 196.5, $p < 0.01$, *two-sided*).

Open-ended questions analysis

Out of the 23 participants, 22 directly mentioned a source object. Most participants correctly named a form of menthol as a component. Whereas less than half of the participants (10/23) mentioned a flower/leafy component, usually referring to roses as a source object. Only 7/23 participants correctly recognized both components. Other noticeable odour associations that were mentioned were different alcoholic smells (6/23, e.g. cleaning supplies, nail polish remover, board markers), rubbery smells (4/23, e.g. car tyre, floor wax) and sweet smells (4/23, e.g. honey, almond paste, liquorice).

Out of the 23 participants 18 were further questioned on the rationale behind their performance on the matching task. Again most of the participants reported object associations as the basis of their choice (12/18 e.g.). A smaller subset was reported to rely on a perceptual link (5/18). The intensity was, for example, directly linked to lightness (e.g. *"the odours that were more intense I categorised as darker green")*. Others made temperature-related analogies (*"Some things smell colder and warmer for example, and therefore would have a colder (blue-ish) or warmer (red-ish) colour."*). A single participant reported using *("When the colours are less bright, it's because I wanted to express my dislike for the odour. For some reason darker colours smell 'bad' in my mind.").*

Discussion

The objective of the present study was to examine the crossmodal effect of the addition of a trigeminal component (menthol) on the colour association of an odour (PEA) in a colour-odour matching paradigm. Hue analysis of the individual odour groups only revealed non-random colour choices for the single menthol conditions (ML, MM and MH) and two of the mixed odour conditions (MLPM, PHMM). Contrary to our predictions the colour choices for the remaining mixes and PEA did not have unanimous colour choices, thereby preventing further analyses of the nature of the shifts between single and mixed conditions. The circular hue analysis suggested that the introduction of menthol led to an increase in circular concentration ($\bar{R}$) when added to PEA (**Table 3**), yet this lacks statistical confirmation. Moreover, as predicted a significant inverse relationship was found between the dimensions of colour lightness and the odour ratings of irritancy (r(229) = -0.14, $p < 0.01$) and intensity (r(229) = -0.23, $p = 0.03$) and a significant positive relationship between that of colour lightness and pleasantness (r(22)) = 0.27, $p < 0.01$). No conclusions concerning dimensional relations could be drawn between the colour saturation and odour ratings. Consistent with our hypothesis, our findings suggest a crossmodal interference stemming from the trigeminal component on participants' colour choices. However, the unexpectedly low unanimity in participants' colour responses prevents us from making substantial claims on the nature of the trigeminal involvement.

The interfering role of menthol as a trigeminal component became most apparent when looking at the seemingly higher circular concentration ($\bar{R}$) of conditions that include menthol versus those that do not (**Figure 4** & **Table 3)**. As can be seen in **Table 3**, the $\bar{R}$ of PEA (PL, PM, PH) increased with the addition of menthol medium (MM). On the other hand, except for MLPM ($\Delta\bar{R}$ = 0.12), the addition of PM to the menthol (low, medium and high) showed a decrease in circular concentration (MMPM:$\Delta\bar{R}$ = -0.30, MHPM: $\Delta\bar{R}$ = -0.51).

While not verified statistically this leaves room for speculation that the addition of menthol caused more unanimity in colour responses in the mixed conditions. On the other hand the addition of PEA to menthol potentially distorted unanimity in colour response. In general, it is hard to draw strong conclusions based on the Hue values with less than half of the odour conditions receiving non-random colour responses.

We also considered a within-participants analysis of the shifts in the HSL and *CIELAB* colour dimensions. Any directional shifts that were found, were either negligible in size with a low variability (e.g. ML-MLPM lightness shift: $\mu = -5.57$, $V = 546.34$), or slightly directional with high variance (e.g. ML-MLPM hue shift: $\mu = -34.05°$, $V = 9582.62$, **Appendix Table 7**). Analysis in the *CIELAB* space revealed similar seemingly non-directional shifts in the distance with high variability (**Appendix Table 8**). Thereby both within-participants analyses remained inconclusive.

Aside from colour matching, the data analysis uncovered various dimensional correlations between odour ratings (intensity, irritancy, and pleasantness) and the lightness dimension of the chosen colours. Aligning with prior research findings (Kemp & Gilbert, 1997; Stevenson et al., 2012; Tamura & Okamoto, 2023) odours that were considered intenser and more irritating were generally coupled to darker colours, while the opposite effect was found between the odour pleasantness and lightness dimensions: more pleasant odours were matched with lighter colours. Interestingly, there also seemed to be a stronger correlation between irritancy and lightness than between intensity and lightness. More extensive statistical approaches could verify this difference's significance, but it could hint at a stronger dimensional relationship between colour dimensions with trigeminal sensations as opposed to the odour intensity that was predicted.

Upon further analysis of the prevalence of correlations with odour ratings across different conditions, it was found that the majority resided within the PEA and mixed conditions. Coincidentally, these were the conditions that received lower confidence in colour choice by participants as opposed to the menthol condition. Moreover, the analysis of the open-ended questions revealed that menthol was mentioned as a source object over twice as much as PEA. It could be that in a similar vein to the findings of Stevenson et al., (2012), participants showed more pronounced correlations between colour dimensions and perceptual attributes with PEA and the Mixes due to their lesser familiarity compared to menthol. The important role of familiarity is further substantiated by the fact that, as expected, the most prevalent reasoning behind the colour-odour matches reported by participants was based on object association. As mentioned earlier, previous research has shown that colour associations are predominantly informed by direct object associations (Goubet et al., 2018). Overall this questions if the interfering effect of the trigeminal component in the form of menthol is caused by its familiarity rather than its trigeminal characteristics.

Aside from sensory correlates with the colour dimensions, odour ratings of intensity and irritancy were taken to assert successful stimulus manipulation. Interestingly, menthol as an odour group was not rated more irritating than PEA, nor were the PEA odour levels mixed with menthol rated higher in irritancy compared to the PEA singles. The within-participants analysis indicated significant differences in rated irritancy between the odour levels of Menthol. However, these differences were not effectively addressed by the post-hoc examination due to the minimal distinctions between individual odour levels. A potential explanation for this discrepancy could be that our concentrations might fall below the threshold required to trigger trigeminal sensations. However, according to (Frasnelli & Hummel, 2005) trigeminal threshold of menthol is at least around 0.8% dilution solved in 40mL of PG presented in 250mL bottles. While presented at lower volumes in our setup, this is still a notably lower concentration thereby dismissing the notion that the trigeminal threshold was not passed. In terms of intensity, there were significant variations in intensity ratings among the different levels of menthol odour, however, a similar level of distinction was not observed within the PEA or mixed odour groups. Lastly, the open-ended questions yielded multiple mentions of unexpected odour descriptors such as alcoholic and rubbery smells. While it might be unclear how exactly this affects the participant's responses, it further emphasizes the importance of rigorous pretesting for the desired results.

After looking at the colour responses, analysis of the saturation values was dropped because of their skewed values toward 100%. Whether or not this is a methodological error or simply the range of saturation in which participants preferred colour choices resided, remains unclear. An indication that our choice of colours might be influenced by the colour picker is evident from previous studies which successfully identified dimensional relationships associated with saturation (Stevenson et al., 2012). Furthermore, it is recognized by prior research that the selection of a colour picker can significantly impact the results of crossmodal matching tasks. For example, Rothen et al. (2013), found that different colour pickers influence sensitivity with which grapheme-colour synaesthesia is diagnosed, with most pickers demonstrating reduced sensitivity. Recommendations for higher sensitivity and specificity are to apply picking methods based on *CIELAB* colour models and subsequent analysis of colour shifts in terms of Euclidean distances. While we did adopt a *CIELAB* analysis, it was not analogous to our colour-picking technique, possibly explaining the negligible shifts between conditions.

Other previous literature has also adapted alternative colour-picking designs which require participants to respond in terms of shift instead of absolute colour responses (Ward et al., 2023). This technique might be more suitable for colour analysis in an odour interference paradigm instead of a regular matching setup. To align the colour-picking mechanism with the space of analysis other kinds of interfaces could be considered, such as the adjusted *CIELAB* circle from Tamura & Okamoto (2023) or *HSLuv* a space functionally similar to HSL, yet dimensionally arranged to the *CIELAB* colour space. In general, the influence of the colour picker used should not be overlooked; its role may have impacted our results and thus warrants careful consideration in future experiments.

The expected result of our experimental design was to influence odour perception through the addition of a trigeminal component, which in turn might affect colour associations. Yet, still much remains unclear about the interaction of odour molecules in mixtures. Thomas-Danguin et al. (2014) have theorized about the different theoretical outcomes that the combination of two odour molecules can have in its perception. Subsequent effects range from different grades of heterogeneous blends in which both odour molecules are perceived, to (partially) homogeneous blends in which one component dominates. Moreover, there are reports in previous literature of a masking effect by odours by a trigeminal component in odour mixes (Cain & Murphy, 1980) which might explain menthol's dominating role in our findings. These theoretical outcomes generally hold up for mixtures containing two components. Yet, realistically speaking odours that are encountered daily contain much more fragrant molecules. An alternative solution to odour mixing could be to use naturally occurring compounds as a base odour. Extracted scents and essential oils usually consist of a wider range of molecules, therefore it would be easier to modulate a single preceptory aspect, such as its trigeminality, without completely warping the odour profile.

Regarding the influence of trigeminality on colour associations, it may be beneficial to first research the response range of potential stimuli. Menthol exhibits just one type of trigeminal effect, contrasting with others such as the burning sensation induced by capsaicin or the tingling sensation caused by carbon dioxide gas (Cayeux et al., 2023). It should also not be overlooked that trigeminal activations are closely related to thermal experiences and therefore temperature-related associations might also mediate colour associations (Michael & Rolhion, 2008). Suitable experimental setups would therefore resemble those of early colour-odour association studies; including a larger subset of trigeminal stimuli and first exploring the general scope of crossmodal correspondences.

In summary, our research confirmed previous findings concerning unanimous colour choices and dimensional relationships between lightness and odour ratings in a colour-odour matching task. Additionally, it has touched upon novelties in the crossmodal explorations of colours and odours, specifically in terms of trigeminal interference. While still much is unknown about the role of trigeminal involvement in these crossmodal interactions between odour and colour perception, we are one step closer to understanding this multisensory phenomenon, which captured the curiosity of scientists and artists alike.

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Appendix

Tables

PEA	Concentration % in PG	**Menthol**	Concentration % in PG
low	8	low	1
medium	17	medium	2
high	30	high	4

Table 6: Concentrations of the conditions. The same concentrations were used in the odour mixes. All odours were solved in 99.5 % Propylene glycol to create a final volume of 15mL in each stimulus flask**.** Compounds used were **l-Menthol:** CAS: 89-78-1, **Phenylethyl Alcohol** CAS: 60-12-8 and 99.5% **Propylene glycol** CAS: 57-55-6.

Condition	**Mean (μ)**	**Median**	**Standard Deviation (σ)**	**Variance (V)**
PL - PLMM				
Hue (°)	-9.67	-14	101.71	10344.98
Saturation (%)	5.29	0	18.83	354.39
Lightness (%)	-4.05	1	17.45	304.33
PM - MMPM				
Hue (°)	-22	-29	86.59	7497.33

Saturation (%)	-7.86	0	37.98	1442.31
Lightness (%)	-1.9	3	20.91	437.23
PH - MHPM				
Hue (°)	26.67	9	91.91	8446.79
Saturation (%)	-8.81	0	21.22	450.15
Lightness (%)	-8.29	-10	21.88	478.8
ML – MLPM				
Hue (°)	-34.05	-37	97.89	9582.62
Saturation (%)	-3.33	0	35.66	1271.75
Lightness (%)	5.57	9	23.37	546.34
MM – MMPM				
Hue (°)	7	-12	101.55	10311.9
Saturation (%)	-3	0	31.95	1021.05
Lightness (%)	2.71	0	27.5	756.11
MH - MHPM				
Hue (°)	-19.29	-22	88.62	7853.92
Saturation (%)	1.19	0	26.67	711.49
Lightness (%)	-1.43	0	24.87	618.72

Table 7: Shifts within participants across the HSL dimensions. Calculated by subtracting the values (*HSL*) of the mixes from their single compound counterpart of the same odour level.

	μ	**V**	**(σ)**
PL - PLMM	73.02	1954.64	44.21
PM - MMPM	69.96	1995.65	44.67
PH - PHMM	71.89	1337.55	36.57
ML - MLPM	71.97	1462.62	38.24
MM - MMPM	77.58	1468.43	38.32
MH - MHPM	66.29	1786.28	42.26

Table 8: Euclidean distances between the odours in *CIELAB* space. Distances were calculated within participants. Above is show the mean, variance and standard deviation of the distances.

Questionnaires

Confidence:

How confident are you that the colour you selected accurately represents the smell you experienced?

The choice was random (1) – Not confident (2) – Slightly confident (3) – Moderately confident (4) – Confident (5) – Very confident (6) – Absolutely certain (7)

Sensory Ratings:

How intense would you describe the odour?

Undetectable (1) – Just noticeable (2) – Mildly intense (3) – Moderately intense (4) – Noticeably intense (7) – Very intense (6) – Overbearingly intense (7)

How pleasant is the odour?

Extremely unpleasant (1) – Very unpleasant (2) – Unpleasant (3) – Neutral (4) – Pleasant (5) – Very pleasant (6) – Extremely pleasant (7)

How irritating to your nose is the odour? For example the experience of smelling a sharp mustard or cold smell of mint could be described as irritating.

Not at all irritating (1) – Slightly irritating (2) – Mildly irritating (3) – Moderately irritating (4) – Noticeably irritating (5) – Very irritating (6) – Extremely irritating (7)

Debriefing interview:

1. During the experiment, did you recognize any of the odours you smelled? If so, please list them below.
2. During the experiment, how did you match the colours to the odours? Was this intuitively? Did you use any tactic or rationale? Please elaborate.