Chem. Senses 38: 175–186, 2013
doi:10.1093/chemse/bjs083
Advance Access publication November 28, 2012

Variability of Affective Responses to Odors: Culture, Gender, and Olfactory Knowledge

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Accepted August 27, 2012

Abstract

Emotion and odor scales (EOS) measuring odor-related affective feelings were recently developed for three different countries (Switzerland, United Kingdom, and Singapore). The first aim of this study was to investigate gender and cultural differences in verbal affective response to odors, measured with EOS and the usual pleasantness scale. To better understand this variability, the second aim was to investigate the link between affective reports and olfactory knowledge (familiarity and identification). Responses of 772 participants smelling 56–59 odors were collected in the three countries. Women rated odors as more intense and identified them better in all countries, but no reliable sex differences were found for verbal affective responses to odors. Disgust-related feelings revealed odor-dependent sex differences, due to sex differences in identification and categorization. Further, increased odor knowledge was related to more positive affects as reported with pleasantness and odor-related feeling evaluations, which can be related to top-down influences on odor representation. These top-down influences were thought, for example, to relate to beliefs about odor properties or to categorization (edible vs. nonedible). Finally, the link between odor knowledge and olfactory affect was generally asymmetrical and significant only for pleasant odors, not for unpleasant ones that seemed to be more resistant to cognitive influences. This study, for the first time using emotional scales that are appropriate to the olfactory domain, brings new insights into the variability of affective responses to odors and its relationship to odor knowledge.

Key words: *affective feelings*, *culture*, *gender*, *hedonic ratings, odor identification*, *olfaction*

Introduction

The perception of odors is frequently associated with affective responses that are prone to interindividual variation. Studies on olfactory abilities (such as identification and sensitivity) usually report two major factors of interindividual variability: gender and culture (e.g., Herz 2009). Here, one of our main aim was to investigate gender and cultural variability specifically in verbal affective responses to odors, using a tool developed recently to evaluate people's feelings related to odor perception (emotion and odor scales [EOSs]; Chrea et al. 2009; Ferdenzi et al. 2011).

In terms of odor detection, there is no conclusive empirical evidence for gender differences (for a review see Doty and Cameron 2009). Nevertheless, where gender differences exist, women are usually more sensitive to odors compared with men (e.g., Koelega 1994; Kobal et al. 2001). For example, women do seem to be more easily sensitized to odors (Dalton et al. 2002), which might explain why they suffer from odor intolerance more than men (Nordin et al. 2004). Studies using verbal reports revealed that, in everyday settings, women care about olfaction more than men do, compared with other sensory modalities (Herz and Inzlicht 2002; Havlicek et al. 2008). Furthermore, women are better at identifying and memorizing odors of various origins, such as food or body odors (Schleidt et al. 1981; Doty et al. 1984; Larsson et al. 2003). Differences in measured and verbally reported olfactory skills may be considered reliable because they have been reported repeatedly and because they are present early in development (Richman et al. 1995; Mallet and Schaal 1998; Choudhury et al. 2003; Ferdenzi et al. 2008).

In terms of emotional responses to odors, women report more frequent evocations of emotional memories by odors and stronger feelings of happiness, sadness, well-being, and reduction of stress as a consequence of smelling odors (Martin et al. 2001). Using presentation of real odors, several studies have confirmed these gender differences in various aspects of olfactory emotional responses. Women give lower hedonic ratings than men to the unpleasant odor of pyridine (Olofsson and Nordin 2004) and to human body odors (Doty et al. 1975, 1982). This greater affective reactivity to odors is also expressed in greater electrophysiological responses in women relative to men (Olofsson and Nordin 2004; Pause et al. 2010). However, not all odors are associated with a greater female affectivity: some odors trigger more positive or negative hedonic responses in one gender, depending on geographical location. Indeed, gender differences seem to depend also on cultural factors, as shown in the National Geographic Smell Survey (Wysocki et al. 1991). Unfortunately, such differences remain difficult to explain and have barely been explored since.

To our knowledge, studies using a more comprehensive approach of odor-related affective feelings (i.e., using a larger variety of affective measures than just hedonicity) have not investigated interindividual variability (e.g., Desmet and Schifferstein 2008; Churchill and Behan 2010; King and Meiselman 2010). Such approaches are nonetheless needed to fully investigate gender and cultural differences in affective responses to odors. Gender and cross-cultural studies in odor perception, in turn, have mainly focused on odor hedonicity, which is only a limited aspect of odor-related affective feelings (Delplanque et al. 2012). Two major conclusions can be drawn from these studies. On one hand, geographic variation in hedonic ratings has been found in two major large-scale studies (Pangborn et al. 1988; Wysocki et al. 1991), with higher pleasantness attributed to odors encountered more frequently or to odors contained in products that have more positive connotations (e.g., an odor present in candies vs. medication). On the other hand, a certain degree of consensus can also be found between cultures; for example, there seem to be convergent negative evaluations of the odors of decaying organic matter, feces, and body odors in European, Asian, and American populations (Schleidt et al. 1988; Schaal et al. 1997). Further investigation with a wider field of affective responses than simply hedonics is now enabled by the EOSs (Chrea et al. 2009; Ferdenzi et al. 2011).

To better understand gender and culture variation of affective responses to odors, it seemed crucial to investigate the link between these responses and perceivers' knowledge about the odors. Indeed, there is some evidence that odor knowledge, that is, odor identification (naming) and familiarity (feeling of knowing), 1) differ as a function of perceiver's sex and culture, and 2) is linked to intensity and valence of affective response to odors. For example, positive relationships between familiarity and pleasantness of odors have been recurrently shown (Jellinek and Köster 1983; Engen 1988; Rabin and Cain 1989; Distel et al. 1999), as well as positive relationships between identification and pleasantness (Ayabe-Kanamura et al. 1998b; Distel and Hudson 2001; Herz 2003; Djordjevic et al. 2008; Rouby et al. 2009). Moreover, shifting the valence of the context of odor presentation has been shown to dramatically change the affective valence of an odor. Herz and von Clef (2001) reported lower hedonic evaluations of the mixture butyric/isovaleric acids when it was labeled "vomit" than when it was labeled "parmesan cheese." Similarly, different beliefs associated to a given odor are strong modulators of how this odor will be perceived (e.g., hazardous vs. healthy attribution; Dalton 1996) and of the perceiver's physiological response (e.g., stimulating vs. relaxing attributions; Campenni et al. 2004). Although other factors might be influential (e.g., physicochemical properties of odorous molecules; Khan et al. 2007), top-down influences are thus believed to be an important factor for the determination of odor affective tone. We propose to investigate this further in this study (which constitutes our second main aim), using more sophisticated measures of affective responses to smells.

In this study, we investigated verbal affective response to odors, using not only classical hedonic ratings but also, and especially, the newly developed EOSs, comprising three published versions for two European countries (United Kingdom and Switzerland) and one Asian country (Singapore). These scales include more than 30 different affective terms, organized in 6 to 7 main categories of feelings and meant to be rated for their perceived intensity resulting from the perception of odors. These affective terms were selected because they were evaluated by participants belonging to each culture as the most relevant of a large set of adjectives (see Chrea et al. 2009; Ferdenzi et al. 2011). They encompass terms related to happiness/well-being, energy, sensuality/desire, and disgust in the three countries, and several other culture-specific categories (see Materials and methods). We first decided to investigate the effects of gender and country on affective ratings, familiarity, and identification, with the hypothesis that women might report stronger verbal affective responses to odors than men. Second, we explored some aspects of the link between odor-related affective feelings (hedonic ratings and EOS ratings) and odor knowledge (familiarity and identification).

Materials and methods

Participants

The participants were recruited from the general public, in a Science Fair in Geneva ("Nuit de la Science"; $N = 151$ females and 59 males, mean age ± standard deviation = 37.8 ± 12.1 years), in the World Museum of Liverpool ($N = 207$ females and 144 males, aged 32.3 ± 13.8 years), and in the Science Center of Singapore ($N = 124$ females and 87 males, aged 30.0 ± 9.0 years). Participants had spent most of their life in the countries where the experiment took place (or in one of the adjacent countries with the same language, e.g., France for the Swiss sample, and Ireland for the British sample). The experiment was performed in the official languages of the countries, namely French in Geneva and English in Liverpool and Singapore. Informed written consent was obtained prior to participation. Committees on Research Ethics of the University of Geneva, the University of Liverpool, and the National University of Singapore approved the study.

Material

Affective ratings

The Geneva, Liverpool, and Singapore EOSs (GEOS, LEOS, and SEOS; Chrea et al. 2009; Ferdenzi et al. 2011) were used to measure affective responses to odors of participants belonging to the respective cultures. The scales consist of 36 or 37 affective terms organized in 6 or 7 categories (cf. Appendix A). Happiness/well-being, energy, sensuality/desire, and disgust are categories common to the three countries; soothing/peacefulness is common to the two European countries and several categories such as sensory pleasure (Geneva), nostalgia and hunger/thirst (Liverpool), intellectual stimulation, spirituality, and negative feelings (Singapore) are country specific. The procedure used to develop the scales and consisting in identifying the most relevant terms among a wide range of emotions *sensu stricto* (see Scherer 2005), moods, personality traits, and attitudes, is described in detail in Chrea et al. (2009) and Ferdenzi et al. (2011).

Odors

A total of 56 odorous stimuli were used in Liverpool and Geneva, and 59 were used in Singapore (Appendix B). They represented a large range of everyday odors including: 1) as many pleasant as unpleasant odors, 2) a high proportion of familiar odors to elicit affective reactions linked to autobiographical memories (including culture-specific odors, such as durian in Singapore), and 3) odors related to various contexts (food: sweet, savory, fruits, spices, drinks, vegetables; and nonfood: cosmetic, household, woody, plants, animals, floral, medicine). The odorous substances, provided by Firmenich SA, Geneva, were diluted in odorless dipropylene glycol to obtain similar subjective intensities (see Delplanque et al. 2008; Chrea et al. 2009). Pen-like devices (Sniffin' Sticks) were filled with 7 mL of each diluted solution and coded with a three-digit number. To limit olfactory fatigue and test duration, each participant evaluated a subset of seven or eight odors (eight subsets in total, see Appendix B). During data collection, the odors were presented in random order.

Procedure

The participants took part in a 20-min session either under a tent outside (Geneva) or in a well-ventilated room (World Museum of Liverpool, Science Center of Singapore). After having smelled each of the seven or eight odors, respondents were asked to rate the intensity of their feelings with the help of the different affective terms. They were presented with the affective terms on a computer interface and gave their answers using a visual analog scale labeled from "not at all" to "extremely," subsequently translated into a 0–200 score. For each odor, affective ratings were followed by familiarity, pleasantness, and intensity ratings on similar scales and, in Liverpool and Singapore only, by free odor identification. In total, each odor was evaluated by 20–32 participants in Geneva, 41–46 in Liverpool, and 24–28 in Singapore.

Score computation

Familiarity, pleasantness, and intensity raw scores were used (comprised between 0 and 200) in the odor-based analyses (scores averaged by odor, see Statistical analyses). In the rater-based analyses (raw scores, see Statistical analyses), the scores were transformed into categorical variables with three modalities (0 for scores comprised between 0 and 66, 0.5 for scores between 67 and 133, and 1 for scores between 134 and 200). The latter transformation was used because the scores did not follow a normal distribution but, based on visual inspection, a trimodal distribution.

Identification scores were computed as follows (data available in Liverpool and Singapore only). For each odor, participants received the score of 0 when they gave no answer or a wrong answer (e.g., "banana" for soya bean), 0.5 when they gave an answer that was almost correct (e.g., "tau hway," which is a kind of tofu pudding made of soya bean curd, for the odor of soya bean, or "orange" for the odor of grapefruit), and 1 when they gave the correct answer (e.g., "soya bean" or "soya bean milk" for the odor of soya bean). For the odor-based analyses, the percentages of correct answers by odor were computed, by summing the scores of all participants having evaluated this odor, dividing it by the number of participants, and multiplying it by 100.

EOS affective responses of each participant to each odor were summarized by using the factor scores, namely the coordinates of a given odor rated by a given participant on the factor formed by a group of affective terms (i.e., a category of feelings such as energy) (M-Plus v.6). All obtained factor scores were then shifted by +100 to obtain positive values only. It must be kept in mind that these summarized (factor) scores are not based on exactly the same individual terms in the three countries (although the categories of feelings bear the same title, cf. Appendix A). In addition, three different affective scores were attributed to each odor for some of the odor-based analyses. Namely, they are the average factor scores of the participants who: 1) successfully identified the odor (i.e., correct and almost correct answers), 2) misidentified the odor (wrong answers), and 3) did not identify the odor (no answer). We considered these average affective scores to be meaningful only when their computation was based on the scores of at least five participants: therefore, odors with insufficient number of participants in at least one of these three subgroups were removed from the analysis (for example, not enough participants provided an incorrect identification for the odor of peppermint, and not enough participants successfully identified the odor of fig). Out of 56 odors, this represented 25 odors in Liverpool, 14 in Singapore, and 38 when the data of both countries were pooled.

Statistical analyses

Rater-based analyses

The first series of analyses consisted in testing the effects of gender and country on the olfactory variables (with R v.2.13.1; see http://www.r-project.org/). Here, raw data (nonaveraged) were used. Because the EOS affective factor scores had a gamma rather than a normal distribution, we used a general linear modeling (GLM) procedure taking into account the gamma distribution. This GLM investigated the main effects of gender and country on EOS scores while controlling for the main effects of odor, familiarity, and intensity. A similar procedure was used to test the interactions gender by country and gender by odor: in these cases, the analyses controlled for the main effects of gender, country when applicable (so that only the effect of the interaction *per se* is tested), and also for odor, familiarity, and intensity. Finally, these main effects and interactions were also tested on familiarity, intensity, pleasantness, and identification while controlling for the main effects of odor only.

Odor-based analyses

This second series of analyses used scores averaged by odor to investigate the links between odor knowledge (familiarity and identification) and affective responses (pleasantness and EOS ratings) (with Statistica v.9). First, we correlated pleasantness ratings with familiarity ratings and percentage of identification (Pearson correlation coefficients). This was performed separately for two groups of odors: those below and those above the median of the average pleasantness rating. We tested the difference between correlation coefficients for both groups of odors. Second, a similar approach was conducted for EOS affective ratings, and in addition, we conducted repeated-measures analyses of variance (ANOVAs), with identification (correct, wrong, not identified) and EOS affective categories (energy, disgust, etc.) as between-odor factors. To qualify the differences between the three groups of identification, repeated-measures ANOVAs with identification as between-odor factor were run for each EOS affective category separately and were followed by post-hoc Tukey honestly significant difference tests. To refine this question at the odor level, we first computed the EOS score difference between the conditions "correct identification" and "no identification." This was done for each odor, and for each of the five affective categories found to significantly vary as a function of identification in the previous ANOVAs. We then performed a cluster analysis (Ward's method on City-block [Manhattan] distances) on 22 eligible odors (i.e., for which average scores were available in all retained EOS categories). With this analysis, different patterns of influence of identification on EOS affective ratings can be identified.

Results

Gender and country differences (rater-based analyses)

Women rated the odors as significantly more intense than men did and they had better identification scores than men ($ps < 0.00025$; all probabilities were Bonferroni corrected, i.e., divided by four as there were four tests for gender, country, gender by country, and gender by odor effects). Women did not differ from men for familiarity and pleasantness ratings. These effects were not odor- or country-dependent (no significant gender by odor/country interactions). On the contrary, men gave higher EOS affective ratings than women on happiness/well-being, sensuality/desire, and energy ($ps < 0.00025$; no significant difference on disgust), and the direction of these differences was maintained even when we conducted the GLM without controlling for other variables (odor, intensity, familiarity). However, the significant gender by country interactions, obtained for happiness/well-being, sensuality/desire ($ps < 0.00025$), energy but also disgust ($ps < 0.0025$), tell us that the gender differences in favor of men are exclusively present in the Swiss sample (Bonferroni-corrected post-hoc contrasts; no significant gender differences in the other countries). For disgust only, there was also a significant gender by odor interaction ($p < 0.0025$) suggesting that the effect of gender was odor-dependent (for detailed results by odor, see Figure 1).

Finally, there were significant country differences on almost all olfactory variables. Pleasantness, familiarity, and intensity ($ps < 0.00025$), but not identification, were significantly lower in Singapore than in both other countries and higher in Geneva than in both other countries (except pleasantness that did not differ between Liverpool and Geneva; post-hoc contrasts). There were significant country differences for all four EOS affective categories ($p < 0.0125$ for disgust and $ps < 0.00025$ for the others). The largest cultural differences are illustrated in Figure 2.

Link between olfactory knowledge and pleasantness (odor-based analyses)

The correlations between familiarity and pleasantness were not significant for unpleasant (U) odors (Geneva: $r_U = 0.36$; Liverpool: $r_U = 0.39$; Singapore: $r_U = 0.33$; see N and ps in Figure 3), but significantly positive for pleasant (P) odors (Geneva: $r_P = 0.71$; Liverpool: $r_P = 0.79$; Singapore: $r_P = 0.80$; Figure 3). Subsequent experiments in four additional geographic areas replicated this pattern (see Supplementary material 1). The correlation coefficients for unpleasant and pleasant odors significantly differed in Geneva ($p < 0.05$), Liverpool ($p < 0.05$), and Singapore ($p < 0.01$; one-tailed tests justified by previous work allowing to predict the direction of these differences; Delplanque et al. 2008).

Unsurprisingly, the percentage of identification (correct or not) and the percentage of correct identification were highly

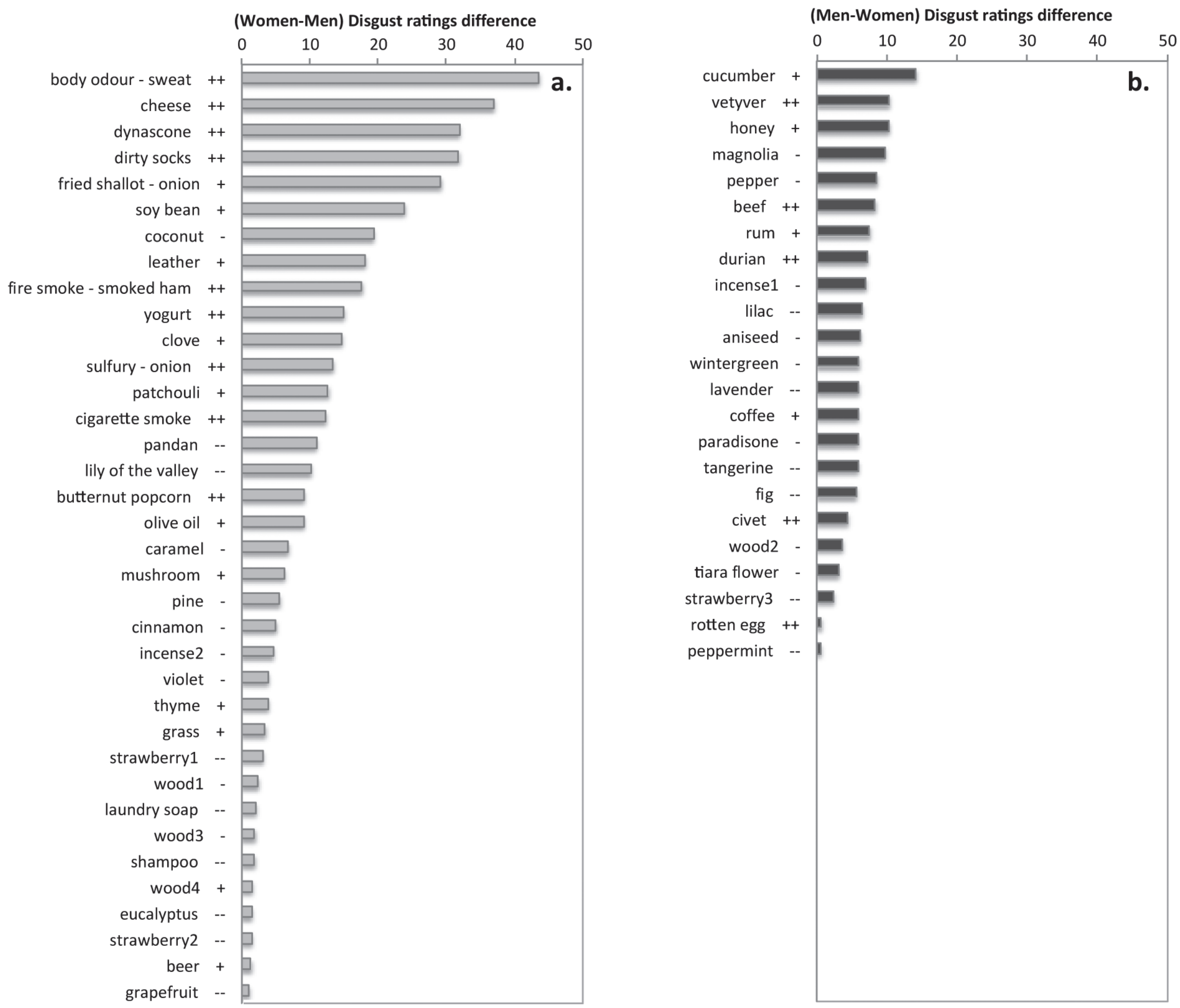

Figure 1 Difference between women and men averaged disgust ratings for each odor. (**a**) Women's higher ratings; (**b**) Men's higher ratings. The symbols ++, +, –, and –– indicate the level of disgust; they correspond to the quartiles of the distribution of the averaged ratings, ++ being the highest scores, –– being the lowest scores, and + and – being intermediate.

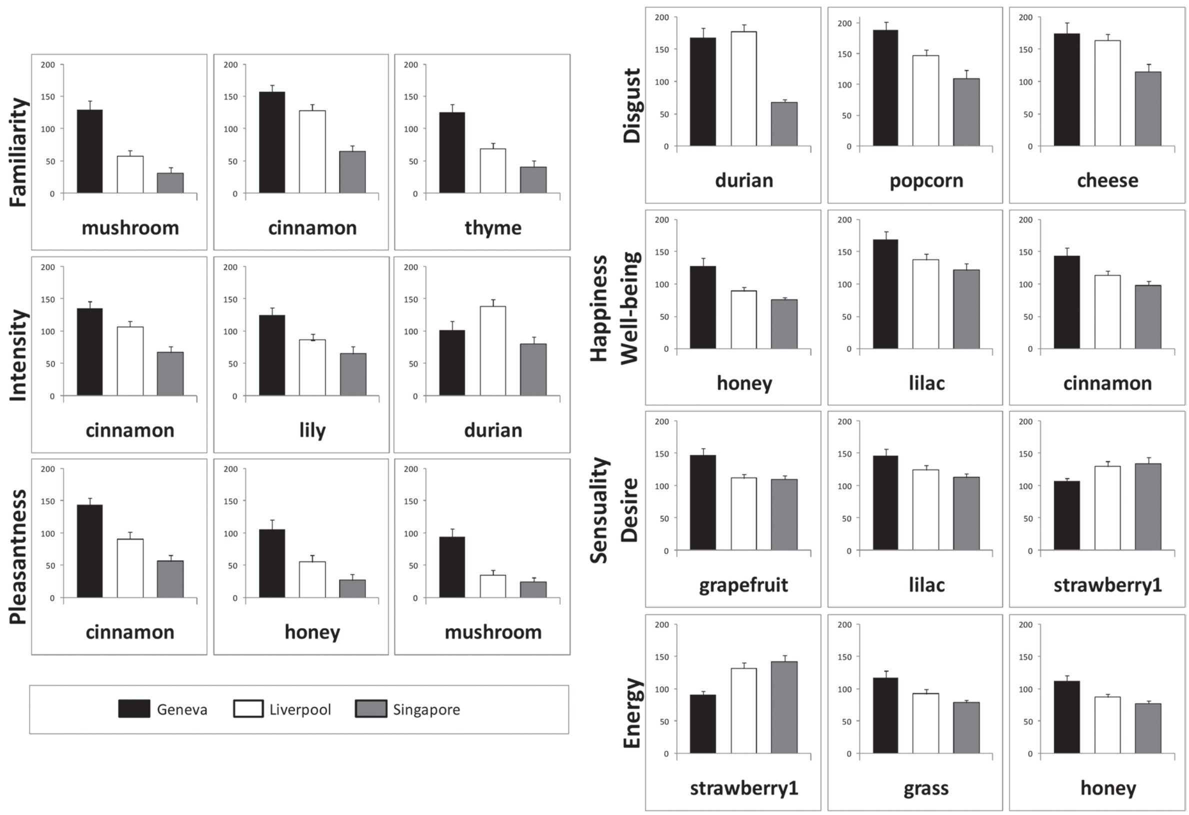

Figure 2 Examples of the largest cultural differences for familiarity, intensity, and pleasantness, and for the EOS affective categories common to the three countries: disgust, happiness/well-being, sensuality/desire, and energy. For each odor, we computed the sum of the absolute differences between countries (subtracting the average ratings by country): the three odors with the highest scores are presented here (mean ± standard error of the mean).

correlated to familiarity (r = 0.85 and 0.66 in Liverpool, and 0.83 and 0.53 in Singapore, respectively, $ps < 0.001$; no identification data in Geneva). We thus tested whether there also was an asymmetry between unpleasant (U) and pleasant (P) odors for identification-pleasantness correlations. It was the case, but the unpleasant-pleasant difference was significant only in Liverpool (identification: $r_U = 0.10$ and $r_P = 0.63$, coefficients' difference significant at $p < 0.05$, one-tailed; correct identification: $r_U = 0.18$ and $r_P = 0.69$, difference significant at $p < 0.05$). In Singapore, although the pattern was similar, that is, correlations were lower for unpleasant odors, there was not significant unpleasant-pleasant difference (identification: $r_U = 0.31$ and $r_P = 0.55$; correct identification: $r_U = 0.23$ and $r_P = 0.58$; coefficients' difference not significant). For both countries, rs_P were significant at $ps < 0.003$, and rs_U were not significant ($ps > 0.094$) (see Supplementary material 2).

Note that the group of pleasant odors was rated as more familiar on average than the group of unpleasant odors (Geneva: 131 vs. 86, $t_{54} = 6.81$, $p < 0.001$; Liverpool: 117 vs. 69, $t_{54} = 6.24$, $p < 0.001$; Singapore: 98 vs. 57, $t_{57} = 6.35$, $p < 0.001$). Pleasant odors also triggered verbal labels more often than unpleasant odors (Liverpool: 51% vs. 38%, $t_{54} = 3.87$, $p < .001$; Singapore: 54% vs. 37%, $t_{57} = 4.17$, $p < .001$), but not significantly more correct labels. Note also that in this whole section, sex-separated analyses showed same results as for the whole group.

Link between olfactory knowledge and EOS ratings (odor-based analyses)

As for pleasantness ratings, EOS affective ratings tended to show in many cases a similar asymmetry between unpleasant (U) and pleasant (P) odors. This asymmetry was again characterized by 1) significant links ($ps < 0.05$) with familiarity/identification/correct identification for P odors and nonsignificant links ($ps > 0.05$) for U odors, and 2) stronger correlation coefficients for P than for U odors (one-tailed tests). Correlations were below 0 for negatively connoted affective categories and generally positive for the other affective categories. If many affective categories met the statistical rules enunciated above, it must be noted that not all did in all countries, which makes the U-P asymmetry for EOS affective ratings a tendency rather than a rule (see Supplementary material 2). Again, sex-separated results did not differ from the whole group.

Further, we compared EOS affective ratings of participants who successfully identified (correctly or almost correctly), misidentified (wrong answer), or did not identify (no answer) the odors. There were highly significant interactions ($ps < 0.001$) between identification (correct, wrong, not

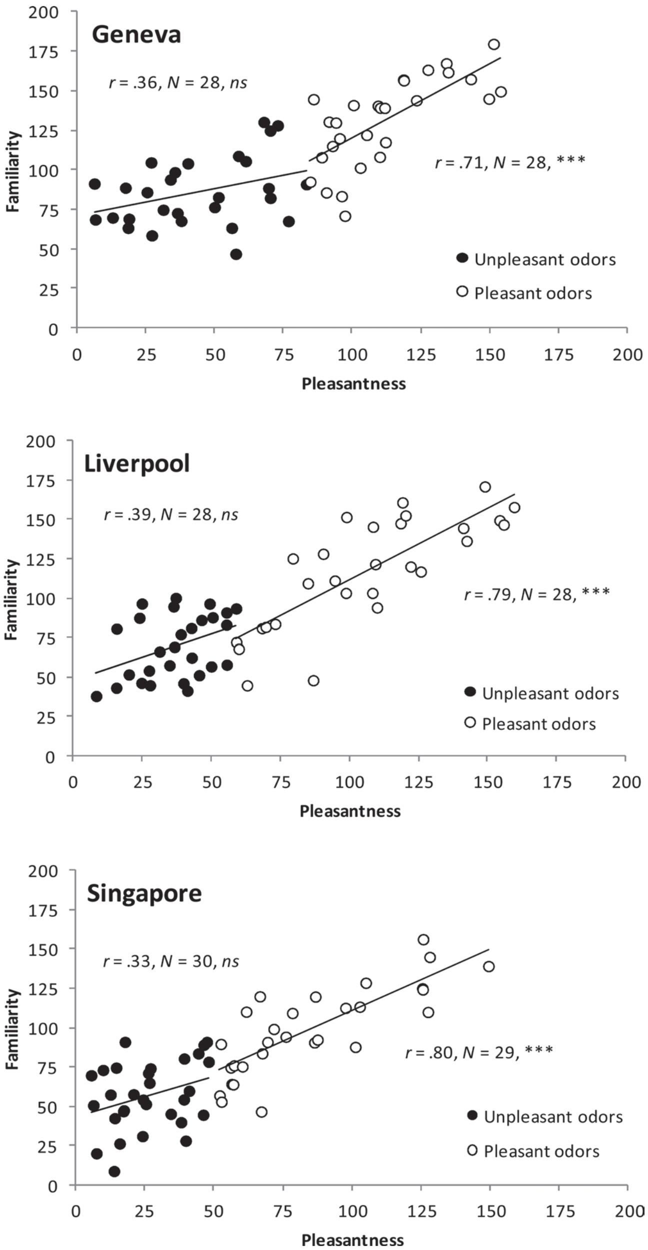

Figure 3 Pearson correlation (*r*) between pleasantness and familiarity for unpleasant and pleasant odors in Geneva, Liverpool, and Singapore. ***$p < 0.000167$ (i.e., 0.001/6, Bonferroni correction), ns: not significant or $p > 0.0083$ (i.e., 0.05/6, Bonferroni correction).

identified) and EOS affective categories (energy, disgust, etc.), when considering the data from Liverpool ($F_{12,288} = 5.44$; 7 affective categories, 25 odors), Singapore ($F_{12,156} = 4.01$; 7 affective categories, 14 odors), and from both countries together ($F_{6,222} = 7.77$; 4 common affective categories, 38 odors). ANOVAs per affective category revealed that identification groups significantly differed for five EOS categories (Figure 4A): happiness/well-being ($F_{2,74} = 7.95$, $p < 0.001$), nostalgia ($F_{2,48} = 5.76$, $p < 0.01$), intellectual stimulation ($F_{2,26} = 3.58$, $p < 0.05$), energy ($F_{2,74} = 6.69$, $p < 0.01$), and disgust ($F_{2,74} = 4.86$, $p < 0.05$). Post-hoc tests showed that compared with unidentified odors, correctly identified odors received significantly lower disgust ratings and significantly higher ratings on the other four EOS affective categories. According to these post-hoc tests, the "wrong" identification category always had an intermediate position (not significantly different from at least one of the other identification groups according to post-hoc tests); it was, therefore, not included in the subsequent cluster analyses and interpretations.

To interpret these average effects further, with a finer approach at the odor level, we ran a cluster analysis on the variation of EOS affective scores (between correctly identified and unidentified), which allowed us to characterize five types of patterns. The number of clusters (five) was set based on visual determination of the inflection point on the plot of linkage distances. Cluster 1, constituted by the odors of tangerine, caramel, strawberry, and peppermint, was characterized by particularly large variations in happiness/well-being (score variation: +32) and intellectual stimulation (+30), the variations in energy (+18), nostalgia (−2), and disgust (−8) being more moderate. Cluster 2 (lavender, grapefruit) was characterized by large variations in happiness/well-being (+63), nostalgia (+42), energy (+39), and small variations in intellectual stimulation (+6) and disgust (−6). In Cluster 3 (laundry soap, civet, eucalyptus, cigarette smoke, cheese), no noticeable variations were found: disgust +7, nostalgia 0, energy –2, intellectual stimulation −2, happiness/well-being −3. Cluster 4 (beer, coffee, shampoo, cream strawberry, floral strawberry) was mainly characterized by variation in nostalgia (+23) and less by variations in happiness/well-being (+14), energy (+12), intellectual stimulation (+3), and disgust (−7). Finally, large variation in disgust (−27) was the main characteristic of Cluster 5 (clove, fried shallot, cucumber, dirty socks, fire smoke/smoked ham, beef), variations in intellectual stimulation (+8), happiness/well-being (+5), nostalgia (+5), and energy (−2) being more limited. To sum up, the results indicate that, although affective feelings triggered by some odors remain unchanged regardless of whether the odor is correctly identified (Cluster 3), affective feelings elicited by other odors are affected: either intellectual stimulation and happiness/well-being are increased by correct identification (Cluster 1), or nostalgia, energy, and happiness/well-being are increased (Cluster 2), or nostalgia only is increased (Cluster 4), or disgust only is decreased (Cluster 5).

Discussion

In this study, we investigated the variability of affective responses to odors, measured by classical hedonic scales, but also, and especially, by the culture-specific EOSs developed recently (Chrea et al. 2009; Ferdenzi et al. 2011). The first aim of our study was to investigate culture and gender differences in odor-induced reported feelings.

First, we found that the odors were less familiar, less intense, and less pleasant in Singapore than in the European

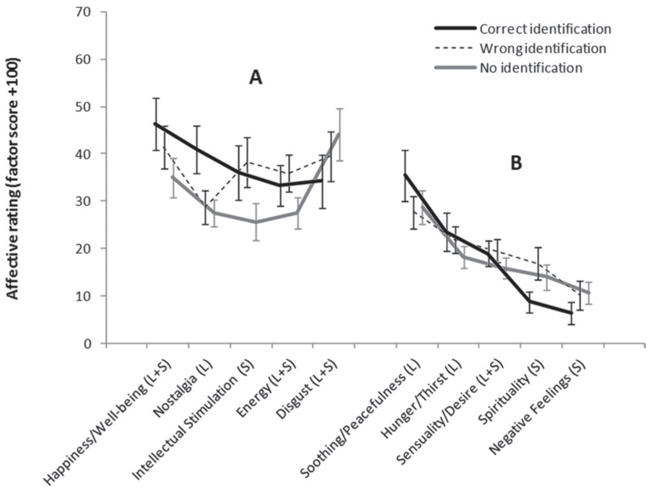

Figure 4 Average EOS affective scores (mean ± standard error of the mean) of participants who successfully identified (correctly or almost correctly), wrongly identified, and did not identify the odors. Averages were computed on 25 odors for affective categories specific to Liverpool (L), on 14 odors for categories specific to Singapore (S), and on 38 odors for categories common to both countries (L + S). (**A**) Affective categories that were significantly influenced by identification; (**B**) Affective categories that were not (repeated-measures ANOVAs per category).

countries (when controlling for the factor odor). This could be due to differences in the olfactory environment of Europe and Asia, with the former being less odorous than the latter. If true, Singaporeans may be more habituated to olfactory experiences and may hence be less sensitive. It cannot be excluded though that these differences could be due to the fact that the odorous substances used in this study were manufactured in a European country and chosen by European experimenters, despite the great effort to choose universal odors (e.g., peppermint, strawberry, caramel) and odors specific to Singapore (e.g., pandan, soy, durian). Regarding the EOS ratings, cultural differences were found to be highly odor-dependent: among others, strawberry elicited less positive affective responses (sensuality/desire, energy, and soothing/peacefulness) in Switzerland than in the other countries, and durian elicited much less disgust in Singapore (see Figure 2), where it is a very popular fruit (in western countries, its unfamiliar odor is often described as decaying matter; see also Ferdenzi et al. 2011).

Second, we found that women rated the odors as more intense than men did, independently of their nationality, which is consistent with some studies on odor threshold detection (Koelega 1994; Kobal et al. 2001; Dalton et al. 2002). Women in the three countries were also found to be better than men at correctly identifying odors, which is an unanimous finding in the literature (e.g., Doty et al. 1984; Larsson et al. 2003) and could be related to gender differences in verbal proficiency. Women indeed have better verbal proficiency/access to semantic knowledge (e.g., Larsson et al. 2003), which is a significant predictor of odor identification (Larsson et al. 2000). However, we found that men expressed more intense feelings to odors. Specifically, they reported stronger feelings related to happiness/well-being, sensuality/desire, and energy. This effect is particularly surprising because 1) one could have hypothesized that women's better identification abilities would enhance their emotional responses to odors (as expected from our results), 2) in other studies, women had more extreme hedonic responses to odors (Doty et al. 1975, 1982; Olofsson and Nordin 2004), and 3) more generally, women tend to verbally report more intense emotions than men (for a review, see Brody and Hall 2008). However, the men's stronger affective verbal responses were only due to the Swiss sample. This could be related to the fact that the proportion of men was lower in Geneva than in the two other countries specifically for the age groups 30–50 years old (25% men, vs. 38% and 47% in Liverpool and Singapore; chi square on the sample sizes: $\chi^2 = 5.10$, $p < 0.05$ and $\chi^2 = 9.60$, $p < 0.01$, respectively) and over 50 years old (14%, vs. 49% and 40% in Liverpool and Singapore; $\chi^2 = 8.23$, $p < 0.01$ and $\chi^2 = 1.89$, $p < 0.20$, respectively); there was no difference for the 16–30 year olds (39% men, vs. 41% and 38% in Liverpool and Singapore; chi square on the sample sizes: $\chi^2 = 0.08$, $p > 0.70$ and $\chi^2 = 0.03$, $p > 0.80$, respectively). Indeed, intensity of both positive and negative experienced emotions is likely to decrease with age (Fernandez-Ballesteros et al. 2010). Thus, the gender difference we found in favor of men might be confounded with an effect of age, which is an aspect of odor-related affective responses that deserves attention in future research.

As suggested in the National Geographic Smell Survey (Wysocki et al. 1991), we also found that the direction of gender differences depended on the odors evaluated. Especially, we found that women had stronger reactions than men on the EOS category disgust for human/animal odors (body odor, dirty socks, leather), food odors related to milk (cheese, yogurt), sulfuric products (fried shallot, onion), and for smoky odors (fire smoke, cigarette smoke; Figure 1a), whereas men were more repelled by vegetal and floral odors (cucumber, vetyver, magnolia etc.; Figure 1b). Although enhanced negative reactions to human odors in women compared with men have already been described in other studies (breath, axillary sweat: Doty 1986; Stevenson and Repacholi 2003), there is no pre-existing evidence of men's greater disgust reactions to particular odors. These differences might be due, at least in part, to the extent to which participants of each sex correctly identified unpleasant odors. Indeed, among the largest differences between the sexes (see Figure 1), odors that were rated more disgusting by women were also generally better identified by them (body odor, cheese: 3–5% more correct answers in women than in men), and similarly for men (beef, rum, durian: 1–3% more correct answers in men). For other odors, how they were categorized during identification might play an important role (independently of the correctness of identification). For example, compared with women, men provided more often negative (incorrect) terms to qualify the odor of honey (such as chemicals/ammonia/urine: 40% of their answers vs. only 20% of women's answers).

This link between identification and affective response to odors was explored further in our study. Our second aim was indeed to investigate the link between affective variables (pleasantness and EOS scales) and odor knowledge measured by familiarity (feeling of knowing) and identification (explicit verbal associations). Overall, we found that higher familiarity and more frequent or correct identification were associated to more positive and less negative affects. This result, reported in the literature for the classical pleasantness scale (e.g., Distel et al. 1999; Herz 2003; even in young subjects: Bensafi et al. 2007) was confirmed here, with both a pleasantness scale and a finer measure of odor-related feelings and proved to be specifically true for pleasant odors. The odors forming the pleasant group were also found to be more familiar and to trigger more identification attempts (correct or not) than the odors of the unpleasant group.

The positive relationship between odor knowledge and hedonic/affective response to odors were probably the consequence of top-down modulation of odor perception, like in studies that manipulated the valence and the availability of verbal information attached to the odor and showed a modulation of hedonic ratings in line with the connotation of the verbal association (e.g., Herz 2003). Here, we assume (also because we noticed that during data collection) that participants tried to identify the odor before starting the affective ratings, even if the identification question was presented after, and that it might have influenced the subsequent ratings. The same might have occurred for familiarity, which represents prior knowledge of the odor in a wider sense than identification (identification is the odor-specific semantic knowledge, probably corresponding to high familiarity, whereas familiarity is the feeling of knowing not systematically associated to a precise odor name; Larsson 1997). These top-down influences have been interpreted before according to the organization of odors in an associative verbal network related to individual's past experience, and to the fact that connotation of the odor source (more than the pure olfactory sensation) or of the context in which the odor was encountered in the past drives emotional responses to the odor (Herz 2003).

However, these influences were asymmetrical. The positive link between odor knowledge (familiarity/identification) and affective ratings (pleasantness, EOS) was revealed only for pleasant odors, not for unpleasant ones. This pattern has been obtained previously in Japanese, German, and Mexican samples (Ayabe-Kanamura et al. 1998a), more recently in a Swiss sample (Delplanque et al. 2008), and negative odors were shown to be less affected than positive ones by cognitive influences (Herz 2003). According to the latter author, the negative odors could have been more quickly and more superficially analyzed due to the unpleasant experience of smelling them, consequently limiting the depth of their cognitive treatment. Alternatively, perception of unpleasant odors may be based more on bottom-up mechanisms, where for example hedonicity of monomolecular odorous compound could depend on its physicochemical properties (e.g., Khan et al. 2007). This would generate a more stable negative sensory sensation and this would make these indicators of potential threats (e.g., odor of spoiled food) less malleable to cognitive influences and more able to maintain a good (and adaptive) level of alertness. Even if complex mixtures of compounds were used, such a phenomenon might be in play for the odors of Cluster 3 (see Results), whose EOS affective ratings, unlike other odors used in our study, were unaffected by identification. This cluster involves some of the most unpleasant odors of the set (civet, cigarette smoke, cheese): they might have very strong intrinsic perceptual properties making them resistant to elaborated cognitive influences. Note that it cannot be excluded that several very positive odors, such as laundry soap and eucalyptus also comprised in Cluster 3, also have particularly resistant perceptual properties. Future research might provide insights into the neurophysiological bases of such variability in susceptibility to cognitive influences.

As mentioned in the Results section, the link between odor knowledge and our newly developed EOS affective categories varied as a function of the category. The cluster analysis provided an illustration of this, showing that the influence of identification on emotional response forms different patterns for different odors. By opposition to Cluster 3 where no influence of identification was found, in Cluster 5 for instance correct identification of the odors (clove, fried shallot, cucumber, dirty socks/cheese, fire smoke/smoked ham, beef) generated an important decrease of the disgust ratings specifically. It has probably more to do with a categorization process, in edible versus nonedible odor source. These odors were all food odors that were of rather low intrinsic pleasantness. It is very likely that only once they were categorized as edible (through correct odor identification) did people feel less reluctant toward them. A similar result was found by Herz and von Clef (2001), and de Araujo et al. (2005) provided evidence that such differences in semantic information provided during odor perception triggered differences in brain activation patterns, namely in the orbito-frontal cortex. It is believed that this brain region provides a top-down signal to the piriform cortex, an important substrate for the perception of odors as perceptual wholes (or objects, see Stevenson and Wilson 2007; Gottfried 2010), thus contributing to build odor representations according to individual's own experience and expectations.

Accordingly, the different clusters we presented in the Results section may correspond to different kinds top-down signals related with odor identification. For example, the common beliefs that lavender and citrus odors, two odors typically associated with aromatherapy products, have relaxing and stimulating positive effects might have been activated when the correct odor names were accessed. This has undoubtedly affected the feeling representation in the direction of higher energy and higher well-being. Similarly, activation of top-down signals related to personal past experiences might have had a role in nostalgia modulation in Cluster 4. Additional information about the content of associated memories would be useful here to understand why the odors of beer, coffee, shampoo, and strawberry specifically triggered more nostalgia when they were correctly recognized.

To summarize, this study brought new evidence of culture and gender differences in odor perception (and especially in odor-related affective feelings, using the new EOSs. It also attempted to relate these differences to variations in odor knowledge. Women had more accurate semantic knowledge than men, which was however not translated into stronger affective responses to odors. Rather, there were some odor-dependent sex differences for the EOS disgust category, in favor of women or of men according to how correctly identified the odors were and to the valence of the odor category chosen to identify the odor. We further showed that, when including all participants, increased odor knowledge was generally related to more positive affects (pleasantness, EOS ratings), certainly due to top-down influences on odor representation. The advantage of using a measure such as the EOS, finer than the classical pleasantness scales, is that we were able to distinguish between groups of odors hypothetically affected by different kinds of top-down influences: especially, cognitive influences related to beliefs about odor properties, and related to categorization (especially edible vs. nonedible). Finally, the link between odor knowledge and olfactory affect was asymmetrical. It was significant only for pleasant odors, not for unpleasant ones that seemed to be more resistant to elaborated cognitive influences. To conclude, this study, for the first time using emotional scales that are specific (and thus appropriate) to the olfactory domain, brings new insights into the variability of affective responses to odors and its relationship to odor knowledge.

Supplementary material

Supplementary material can be found at http://www.chemse.oxfordjournals.org/

Funding

This work was supported by Firmenich and the National Center of Competence in Research (NCCR) Affective Sciences financed by the Swiss National Science Foundation.

Acknowledgements

The authors wish to thank Andrew Giger and Mike Graham for enabling the study to be conducted in the Science Center in Singapore and in the World Museum in Liverpool, respectively. Pearlene Lim (in Singapore) and Ruth Cox (in Liverpool) were of great help in analyzing the odor identification responses. Nadine Gaudreau, William Jolly, Olivier Rosset, and Dajana Kapusova are thanked for their valuable technical help.

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Appendix A

Categories and terms of the EOSs

GEOS—Geneva EOS (36 terms)	
1. (Happiness-Well-being)*	attracted, feeling awe, happiness, pleasant, pleasantly surprised*, well-being
2. (Disgust)*	angry, dirty*, disgusted*, dissatisfaction, irritated, sick*, unpleasant*, unpleasantly surprised*
3. (Sensuality-Desire)*	admiration, desire*, excited, in love*, romantic*, sensual*, sexy*
4. (Energy)*	clean, energetic*, invigorated, refreshed*, revitalized*, stimulated, shivering
5. (Soothing-Peacefulness)	light, reassured, relaxed*, serene, soothed
6. (Sensory Pleasure)	amusement, nostalgic, salivating
LEOS—Liverpool EOS (37 terms)	
1. (Happiness-Well-being)*	in a good mood, pleasantly surprised*
2. (Disgust)*	dirty*, disgusted*, nauseous, repelled, sick*, uncomfortable, unpleasant*, unpleasantly surprised
3. (Sensuality-Desire)*	attracted, desire*, in love*, lustful, romantic*, sensual*, sexy*, to feel intimacy
4. (Energy)*	clean, energetic*, refreshed*, rejuvenated, revitalized*, stimulated
5. (Soothing-Peacefulness)	comforted, dreamy, drowsy, meditative, peaceful, protected, relaxed, soothed
6. (Nostalgia)	nostalgic, sentimental
7. (Hunger-Thirst)	famished, salivating, thirsty
SEOS—Singapore EOS (36 terms)	
1. (Happiness-Well-being)*	comforted, happiness, pleasant, pleasantly surprised*, relaxed, well-being
2. (Disgust)*	dirty*, disgusted*, horrible, irritated, sick*, uncomfortable, unpleasant*, unpleasantly surprised*
3. (Sensuality-Desire)*	admiration, adoring, charmed, desire*, in love*, romantic*, sensual*, sexually aroused, sexy*
4. (Energy)*	energetic*, refreshed*, revitalized*
5. (Intellectual Stimulation)	amusement, fascinated, interesting
6. (Spirituality)	religious feeling, spiritual feeling
7. (Negative Feelings)	angry, boredom, depressed, sad, stressed

* Terms and categories common to the three countries.

Appendix B

Odorous substances (Firmenich SA) and their concentrations (in volume–volume percentage)

	% V/V		% V/V
SUBSET 1		SUBSET 5	
Beer	20	Beef	1
Pepper	Pure	Grass	20
Peppermint	20	Honey	Pure
Sulfury, onion (sclarymol)	1	Pandan[a]	10
Tangerine	20	Paradisone	Pure
Tiara flower	Pure	Pine	Pure
Wood 1 (Agarwoodsmoke)	20	Strawberry 2	10
		Body odor, sweat	Pure
SUBSET 2		SUBSET 6	
Cheese	1	Cigarette smoke	50
Coconut[a]	10	Civet	10
Coffee	20	Fig	10
Durian	10	Incense 2 (Chinese incense)	20
Grapefruit	20	Rum	10
Lavender	10	Wintergreen (methyl-salicylate)	10
Lilac	10	Wood 3 (Wolfwood)	Pure
Vetyver	20		
SUBSET 3		SUBSET 7	
Aniseed (anethol)	20	Cinnamon	20
Butternut popcorn	10	Cucumber	20
Incense 1	50	Fire smoke, smoked ham (cade oil)	10
Mushroom (carbinol)	5	Laundry soap (Ariana)	1
Rotten egg (sulfox)	5	Leather	5
Shampoo (Defi)	10	Soy bean[a]	20
Wood 2 (Firsantol)	20	Violet	10
		Yogurt	10
SUBSET 4		SUBSET 8	
Clove (eugenol)	20	Caramel	20
Dirty socks (isovaleric acid)	1	Dynascone	10
Eucalyptus	20	Magnolia	20
Fried shallot, onion	20	Olive oil	20
Lily of the valley	10	Strawberry 3 (Floral strawberry)	5
Patchouli	10	Thyme	20
Strawberry 1 (Cream strawberry)	5	Wood 4 (Landeswood)	5

[a]In Singapore only