

The Color of Odors

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The interaction between the vision of colors and odor determination is investigated through lexical analysis of experts' wine tasting comments. The analysis shows that the odors of a wine are, for the most part, represented by objects that have the color of the wine. The assumption of the existence of a perceptual illusion between odor and color is confirmed by a psychophysical experiment. A white wine artificially colored red with an odorless dye was olfactory described as a red wine by a panel of 54 tasters. Hence, because of the visual information, the tasters discounted the olfactory information. Together with recent psychophysical and neuroimaging data, our results suggest that the above perceptual illusion occurs during the verbalization phase of odor determination. © 2001 Academic Press

Key Words: odor identification; color; perceptual illusion; lexical analysis; psychophysical; wine.

INTRODUCTION

Smell is often considered a peculiar sensory modality, the main function of which remains to be specified. A number of structural characteristics distinguish olfaction from other sensory modalities. The peripheral olfactory system has a low specificity for substrate. A single receptor recognizes multiple odorants, and a single odorant is recognized by multiple receptors (Malnic et al., 1999). The projection of peripheral information toward the central structures is primarily ipsilateral. Olfactory information is the only sensory information that is integrated directly into cortical regions without a preliminary processing in the thalamus. Olfactory neuronal transduction, carried out by unmyelinated axons, is the slowest of the nervous system. Olfactory detection (about 400 ms) is approximately 10 times slower than visual detection (Herz & Engen, 1996). Moreover, the definition of olfactory images is relatively weak (approximately 50,000 mitral cells) compared with the million pixels per visual image represented by the retinal cells (Holley & MacLeod, 1977).

These particular structural characteristics are associated with specific functional properties. It has been shown that olfactory perception induces nonolfactory pro-

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cesses. Odors can unconsciously modify behavior (Epple & Herz, 1999; Pauli et al., 1999; Spangenberg et al., 1996), generate emotions (Herz, 1998; Kirk-Smith et al., 1983; Vernet-Maury et al., 1999), or evoke past situations (Chu and Downes, 2000). Smell is probably the sensory modality most difficult to verbalize (Wippich et al., 1989). Human beings possess an excellent ability to detect and discriminate odors, but typically have great difficulty in identifying specific odorants (Richardson & Zucco, 1989). This difficulty becomes insurmountable as the complexity of the odor source increases (Jinks & Laing, 1999). Experts and trained participants who can match single-component stimuli with hit rates close to 100% appear capable of identifying no more than three to four of these components in odor mixtures (Livermore & Laing, 1996). In contrast to other sensory modalities, the fact that there are no specific terms to describe odors supports the idea of a defective association between odor and language. Odors take the name of the objects that have these odors. In this article, the term "odor descriptor" will refer to the name of the object used by a subject to identify an odor. The weak relationship between odors and language is probably due to the proposed lateralization of brain areas involved in the processing of language and smell. Indeed, for most people, linguistic processing is primarily a left hemisphere activity (Deppe et al., 2000; Frost, et al., 1999; Knecht, et al., 2000; Lee et al., 1999) while odor perception is more lateralized to the right hemisphere (Dade et al., 1998; Herz et al., 1999; Hummel et al., 1998; Kobal & Kettenmann, 2000). However, data from the literature show that there is a controversy on this last point (Brand, 1999; Brand et al., 1999).

We therefore propose that, in most cases, smell is a sense unlikely to provide sufficient information to generate a consciously reasoned decision, as it is for other sensory modalities. Without considering it to be a minor sense, it is probable that smell provides specific information that can modify the perception constructed by the other sensory modalities. The strong influence of visual information on the perception of odors illustrates the dependence of smell on more reliable information. Data from the literature show that color strongly influences the qualitative (Gilbert et al., 1996; Stillman, 1993; Zellner et al., 1991, Zellner & Whitten, 1999), quantitative (Kemp & Gilbert, 1997; Zellner & Kautz, 1990), and hedonic (André et al., 1970; Christensen, 1983; Léon et al., 1998) determination of odors.

In everyday life and in some professional activities (sensory analysis, enology, and perfumery), humans make use of their abilities to identify odors. In doing so, they use olfactory information to make judgments and decisions. Results from sensory analysis studies show that human performances in describing odors are not very reliable nor easily usable (Lawless, 1999), which agrees with physiological data. The determination of odor descriptors is characterized by significant interindividual differences (Laska & Teubner, 1999) and by a marked influence of contextual parameters (Brochet & Morrot, 1999; Dalton, 1996).

Enological tasting is a current practice in which single persons may provide a large body of wine tasting comments. These comments are based on an analytical description of the visual, olfactory, and gustatory properties of wines (Vedel et al., 1972). The analysis of wine tasting comments is thus a tool well adapted for studying interactions among various sensory modalities. Data show that aroma determination is modified according to whether the color of wine is obscured to the subjects by the use of opaque glasses (Williams et al., 1984). Moreover, the acceptance of the odor of a wine is significantly correlated to its color (Pokorny et al., 1998). Our study first focuses on the influence of vision on smell by carrying out a lexical analysis of four wine experts' tasting comments.

The lexical analysis used the ALCESTE methodology (Reinert, 1986). The analysis is based on the statistical distribution of words in a text. It is postulated that words

association depends on the context in which these words are used. Classes of co-occurrent words are then extracted from the text to provide an output in the form of lexical fields. The meaning associated with the lexical fields indicates the context in which the enunciators carried out their analysis. In other words, it is possible to know the “point of view” of the enunciator and the representations he used as a reference (Reinert, 1993, 1994). This point of view may be considered a representation of the personal and social representations (Moscovici, 1984) which, by being unconsciously integrated into perception, associates with it a semantic content. This kind of analysis may thus provide information on the cognitive processes implied in the construction of perception. In our study, we demonstrate evidence of a semantic odor–color association using lexical analysis and confirm it by a psychophysical experiment.

MATERIALS AND METHODS

Lexical Analysis

Alceste provides a powerful method for analyzing statistically the co-occurrence of words in a corpus of text. As a result, it produces sets of words that should be considered as contexts having similar semantic nature.

The lexical analysis of the four corpuses of wine tasting comments was carried out with software ALCESTE v.4.0 (distributed by the IMAGE company, Toulouse, France), on a microcomputer Modulux PC (Pentium processor, 200 MHz).

The corpuses treated by lexical analysis come from three wine journalists (two in French and one in English) and from one French wine maker.

Corpus D: French comments resulting from *La lettre de Gault & Millau*. The 3000 tasting comments were written by Jacques Dupont between 1991 and 1996.

Corpus H: French comments from the *Guide Hachette du vin*. In that guidebook, the wines are tasted by small groups of professionals. The resulting comments are used for drafting the final comment. The corpus used in our study consists of a random selection of 3,000 tasting comments among the 32,000 comments published during the past 10 years.

Corpus P: English comments published in *The Wine Advocate*. The 7000 tasting comments were written by Robert Parker.

Corpus V: Personal comments from a French wine maker. The 2000 tasting comments were written over a 3-year period.

The input files contained the entire texts of all tasting notes. In order to allow an easier interpretation of the output lexical fields, ALCESTE allows representative variables to be associated with parts of the text. Each tasting comment is preceded by a line containing the representative variables associated with the tasted wine, i.e., color of the wine (red or white), year, region of origin, and score. These variables do not influence the results, but they are associated, at the end of the analysis, with specific lexical fields.

Each corpus was individually analyzed with the standard profile proposed by the software. The main steps of the analysis are (1) Reduction of the words to their roots (lemmatization) and elimination of rare words. (2) Partition of the text into “context units,” each having approximately the length of a sentence. The units are then classified according to the distributions of their words. In fact, the analysis is performed in parallel with two different partitions in order to check that the result do not depend on partition itself. (3) Groups of cooccurrent word (lexical fields) are determined by a hierarchical cluster analysis. The appropriation of each word to its lexical field is validated by its association chi-square value.

Semantic aspects are not taken into account by the method, so that the analysis is not language-dependent. It follows that ALCESTE lexical analysis is possible with texts written in any language other than those not structured into words (Beaudoin & Brochet, 1994). In the lemmatization step, the software uses integrated dictionaries for each language. It is thus not possible to analyze a corpus of texts in different languages. For this reason, the three French corpuses were treated both individually (see above) and as a single corpus.

The output from ALCESTE includes the list of words in each lexical field. The meaning of lexical fields is determined from these words. The association of representative variables with different lexical fields is a function of their association chi-square values. A dendogramme resulting from hierarchical cluster analysis shows the hierarchical division of the lexical fields.

Comparative Tasting

The two wines used for the experiment were Bordeaux wines (AOC "Bordeaux," vintage 1996), containing *sémillon* and *sauvignon* grapes for the white wine (wine W), and *cabernet-sauvignon* and *merlot* grapes for the red wine (wine R).

Part of the white wine was colored red (wine RW) with 2 g/L of purified grape anthocyanins (E 163, ANTOCIAL, SEFCAL, 30760 Saint-Julien de Peyrolas, France). Wine W was treated in the same way as wine RW (stirring and oxygenation) except coloring.

The neutrality test of the dye was carried out by 50 people recruited on the ENSIA Massy campus. The sex ratio was 1:1. In order to verify that the anthocyanins had no perceptible odor, colored white wine was compared to normal white wine by means of triangular tests in opaque glasses. Each subject completed one block of six trials (the six possible arrangements), presented in random order with three random digits indicated on each glass. The subjects tasted the wines in individual booths illuminated with red light. The subjects received 50 FF for their participation in the test.

The wine comparison test was carried out in two sessions separated by 1 week. In order to get round the interindividual chemosensorial differences of the tasters, the comparative test did not require the use of a consensual language. Indeed, if individual odor spaces can exist, individual differences are too great to establish a representative odor space for a whole group (Berglund et al., 1973). During the second session, tasters were asked to use the same list of terms as they themselves chose to use during the first session. This gave us the possibility to compare the descriptions in the two experiments, while allowing the tasters to describe the wines with their own terms.

The wine comparison test was carried out by 54 undergraduates from the Faculty of Oenology of the University of Bordeaux. The sex ratio was 1:1. The subjects were not told in advance that there would be only two sessions. The wines were presented in clear AFNOR glasses, under artificial white lighting. The subjects were seated in individual booths and were allowed to taste as they wished. In each session, they received two wines and they had the possibility of comparing them during the whole session.

During first session, the subjects were requested to draw up a list of odor descriptors for wine W and R. A list of descriptors was supplied to them. The subjects had the possibility of using the descriptors from that list or one of their own choosing. For each descriptor, the subjects had to indicate which of the two wines most intensely presented the character of this descriptor. For the second session, each subject received his/her own list of descriptors, from the first session, given in alphabetical order and without indications concerning the wines. The two wines then proposed were W and RW. The subjects were asked to indicate for each descriptor of their list which of the two wines most intensely presented the character of this descriptor.

RESULTS

Lexical Analysis

The dendogrammes of the various lexical fields from ALCESTE are shown on Fig. 1. The number of lexical fields obtained for corpuses D, H, P, and V are 5, 4, 3, and 6, respectively. The results of the cluster analysis have been published previously (Brochet & Dubourdieu, 2000). The number and nature of lexical fields for each corpus are identical for the two different partitions in the standard analysis, which shows that the results do not depend on preliminary treatment of data. The semantic contents of the various lexical fields are briefly described under Discussion and have been extensively published elsewhere (Brochet & Dubourdieu, 2000).

As shown in Fig. 1, the first segmentation clearly separates the lexical fields associated with the descriptive variable "white wine" from those associated with the descriptive variable "red wines". When the three French corpuses were processed as a single body, the ALCESTE output consisted of only two lexical fields, one for the red wines and the other for the white wines.

The words relating to the description of odors were extracted from the lexical fields belonging to the two color categories. The odor descriptors specifically associated with the descriptive variables "red wine" and "white wine" of corpus D are listed in Table 1. The odor descriptors that describe the red wines are for the most part represented by red or dark objects, while those that describe the white wines are

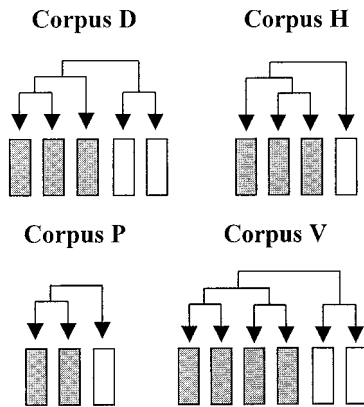


FIG. 1. Dendogrammes of the lexical fields generated by ALCESTE lexical analysis for four wine tasting comments corpuses. The lexical fields specifically associated with the representative variable “Red wine” or “White wine” are in gray and white, respectively. The first partition (i.e., the most significant) occurs, in the four corpuses, between the lexical fields specifically associated with the representative variable “Red wine” or “White wine”.

mainly represented by yellow or clear objects. This characteristic is common to the four analyzed corpuses.

Neutrality of the Dye

Of 300 triangular tests, only 120 were correctly identified as the odd sample, indicating no significant differentiation. Furthermore, none of the 50 subjects correctly identified more than 4 of 6 triangular tests, which indicates no significant differentiation among subjects. It is therefore concluded that wines W and RW are perceived as identical and that the dye can be regarded as having no odor.

Wine Comparison Test

The results of the comparative test are presented on Fig. 2. During the first session, the subjects chose odors represented by red or dark objects to describe wine R and yellow or clear objects to describe wine W. During the second session, the subjects generally used the odor descriptors they had used to characterize wine R to describe the wine RW. Moreover, in their olfactory description of wine RW, they eliminated the descriptors they had used for wine W. Figure 3 shows that olfactory terms corresponding to white (or light) and red (or dark) objects were used to describe wines W and RW, respectively.

DISCUSSION

The lexical analysis of the tasting comments of four wine professionals provided a representation of their wine perception. The lexical fields associated with these representations are different in number (Fig. 1) and content. A detailed analysis of the latter has been published elsewhere (Brochet & Dubourdieu, 2000). In brief, it was observed that the lexical fields represent prototypic wines and that their categorization is primarily determined by hedonic criteria. From a cognitive point of view, this result shows that the mechanism used to judge wines is closer to pattern recognition than descriptive analysis. The differences observed between subjects show that

TABLE 1

List of the Most Often Used Olfactory Terms from the Lexical Fields Associated with the Respective Variable "White wine" or "Red wine" in Corpus D

White wine				Red wine			
Descriptors (French)	Descriptors (English)	Occ. corpus	% group	Descriptors (French)	Descriptors (English)	Occ. corpus	% group
Miel	Honey	151	100	Chicorée	Chicorey	6	100
Citron	Lemon	103	100	Charbon	Coal	5	100
Pamplemousse	Grapefruit	43	100	Povoine	Peony	27	88.89
Paille	Straw	30	100	Pruneau	Prune	48	87.5
Banane	Banana	27	100	Myrtille	Bilberry	46	86.96
Litchi	Lychee	23	100	Framboise	Raspberry	173	86.71
Pétrole	Petroleum	21	100	Girofle	Clove	19	84.21
Acacia	Acacia	18	100	Cerise	Cherry	309	83.5
Aubépine	May blossom	17	100	Fraise	Mills	101	83.17
Soufre	Sulfur	17	100	Cèdre	Cedar	41	82.93
Buis	Boxtree	14	100	Musc	Musk	25	80
Arachide	Peanut	14	100	Havane	Havana	15	80
Mirabelle	Mirabelle plum	14	100	Chocolat	Chocolate	61	78.69
Mangue	Mango	13	100	Violette	Violet	154	77.27
Melon	Melon	12	100	Cacao	Cocoa	35	77.14
Tilleul	Lime tree	9	100	Cassis	Blackcurrant	245	75.92
Beurre	Butter	97	98.97	Tabac	Tobacco	61	75.41
Pêche blanche	White peach	38	97.37	Cannelle	Cinnamon	27	74.07
Pêche jaune	Yellow peach	38	97.37	Groseille	Red currant	108	73.15
Coing	Quince	36	97.22	Griotte	Griotte	39	64.1
Agrume	Citrus fruit	141	97.16	Goudron	Tar	42	61.9
Poire	Pear	68	97.06				
Ananas	Pineapple	27	96.3				
Noisette	Bazelnut	102	96.08				
Abricot	Apricot	83	95.18				
Pomme	Apple	99	94.95				
Hydrocarbure	Hydrocarbon	19	94.74				
Amande	Almond	100	94				
Fleur	Flower	46	93.48				
Noix	Walnut	26	92.31				

^a For each term, total number of occurrence in the corpus (Occ. corpus) and percentage of attribution in the lexical fields associated with the representative variable "White wine" or "Red wine" (% group) are listed.

each expert uses different referents to describe the wines, which emphasize the importance of the interindividual differences and the subjective character of flavor description.

We focused on a particular aspect of the results of the lexical analysis, showing that the only common point between the four corpuses is the use of a different vocabulary to describe white and red wines. The fact that, when the three French corpuses are processed together as a single body, the ALCESTE output consists of only two classes, one for red wines and the other for white wines, has two meanings. On one hand, at the lexical level, the enunciators integrate the color in their description of the wines by an identical process. On the other hand, the enunciators have different discursive strategies for all the aspects that do not relate to the wine color.

From a sensory viewpoint, the fact that the authors used a different vocabulary to describe white and red wines is relatively surprising. Indeed, tests carried out with opaque glasses show that identifying the color of a wine without the assistance of sight is not an easy task (Sauvageot & Chapon, 1983). Our own experiments of color

		Descriptors used for wine W	Descriptors used for wine RW
White wine descriptors	LIT	***	
	FLO	•	
	MIE	•	••
	AGR	••	
	FRU	•	•
	POM	••	
	BAN	••	
	BON	•	
	POI	•	
	ANA	••	
	PAM	••	
	ACA	•	
	PEC	•••••	••
	BEU	•	
Red wine descriptors	EPI		••••••••••
	BOI	•	
	CAS		••••••••••
	FRA		••••••••••
	CER		••••••••••
	PRU	•	••••••••••
	FRS		••••••••••
	VAN		••••••••••
	CAN		••••••••••
	POV	•	••••••••••
	ANI		••••••••••
	REG		••••••••••

FIG. 2. Distribution of the odor descriptors used by at least 3 different subjects during the second session of the wine comparison test for the description of W and RW by 54 subjects. Labels “White wine descriptors” and “Red wine descriptors” contain the terms used for describing the W and the R wines during the first session, respectively.

White wine descriptors: LIT = litchi (lychee); FLO = floral (floral); MIE = miel (honey); AGR = agrume (citrus fruit); FRU = fruit de la passion (passion fruit); POM = pomme (apple); BAN = banane (banana); BON = bonbon (candy); POI = poire (pear); ANA = ananas (pineapple); PAM = pamplemousse (grapefruit); ACA = acacia (acacia); PEC = pêche (peach); BEU = beurre (butter). Red wine descriptors: EPI = épice (spice); BOI = boisé (wooded); CAS = cassis (blackcurrant); FRA = framboise (raspberry); CER = cerise (cherry); PRU = pruneau (prune); FRS = fraise (strawberry); VAN = vanille (vanilla); POV = poivre (pepper); ANI = animal (animal); REG = réglisse (liquorice).

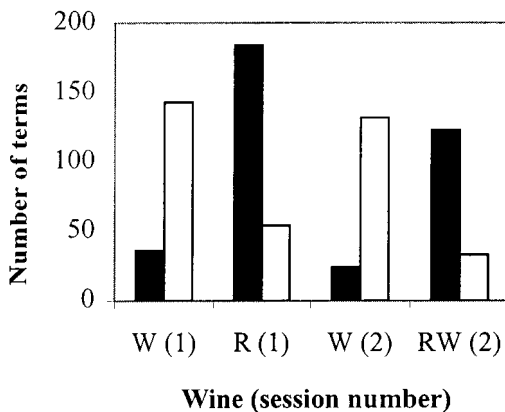


FIG. 3. Distribution frequency of olfactory terms representative for red/dark objects (solid bars) and yellow/light objects (open bars) as used for wine description in session 1 [W(1) and R(1)] and session 2 [W(2) and RW(2)] of the wine comparison test.

determination of a wine without sight (data not shown) brought us to the same conclusions as Sauvageot and Chapon (1983), and we found that the rate of success varies significantly according to the wines used. In this experiment, subjects had to smell a wine and, from their global perception, decide on the color (red or white) of the wine. No odor identification was associated with this task. Our various experiments lead us to propose a percentage value close to 70% of success for this task (chance would score 50%). Even if the subjects succeed better than chance in this task, the flavor of a white wine was not clearly distinguished from that of a red wine. This result appears to be in contradiction with the fact that the four wine experts have led to agreement on classes of terms that separate white wines from red wines. We conclude that categorizing a wine as white or red without the help of the sight does not imply the identification of the odors of this wine. It rather suggests that the two tasks are very likely processed by different mechanisms.

The examination of the specific vocabulary for smell from the lexical fields generated by ALCESTE shows that the four tasters actually used a common mechanism to describe the odors of the wines. The objects chosen to represent the odor of a wine are, for the most part, the same color as that wine.

Until now, ALCESTE software has been used mainly in the field of social sciences. The lexical fields generated by this analysis can be regarded as representations of the social representations, “collections of definitions of the world and its parts, catalogues of the possible forms, which allow the subject to orient himself and to act in its environment” (Lahlou, 1998). These referents, although not explicitly present in the wine tasting comments are found by the lexical analysis. Our analysis of sensory discourse shows the existence of an implicit mechanism for the processing of sensory data. As in the case of social representations, color is used implicitly in the verbalized act of determination of odors. The color can be found in the enunciator’s discourse without it being consciously stated. The ALCESTE software is therefore a well-adapted tool for evidencing from the discourse, the unconscious processes involved in cognitive construction.

Evidence of the relationship between the perceived odor and the color of a wine initially led us to hypothesize that the color of a wine directs the identification of its odor. We tested our hypothesis by asking 54 subjects to identify in parallel the odors of a white wine and the same white wine colored red.

The results of our experiment were consistent with our hypothesis. The white wine was perceived as having the odor of a red wine when colored red. The wine’s color appears to provide significant sensory information, which misleads the subjects’ ability to judge flavor. Moreover, the mistake is stronger in presence than in absence of access to the wine color.

The observed phenomenon is a real perceptual illusion. The subjects smell the wine, make the conscious act of odor determination and verbalize their olfactory perception by using odor descriptors. However, the sensory and cognitive processes were mostly based on the wine color. The phenomenon we observe is similar to an other well-known perceptual illusion: the size–weight illusion (the smaller of two equally weighted objects is judged to be heavier when lifted). In both cases, modifying one property of an object (size or color) gives the perception that an other property (weight or odor respectively) of this object has changed.

This perceptual illusion is easily seen in wine tasting comments published in specialized magazines. In most cases, one can predict the color of the wine tasted according to the odor descriptors. We considered here that the wines are roughly divided in two categories: the white and the red wines. A more thorough examination of the tasting comments shows that the influence of color on the identification of flavor is more precise. Indeed, the objects representing the wine color have a tendency to have

a color close to that of the wine. For example, old wines with a “*tuilée*” (tiled) color generally have orange or maroon fruit flavors (dry fruits, grooves, etc.), while “*rosé*” wines have pink fruit flavors (red currant, raspberry, etc.)

Evidence of the above perceptual illusion opens future prospects for experimentation on the study of interactions between color and smell similar to studies on the Stroop effect (Jensen & Rohwer, 1966), concerning the interaction between language and color. It is probable that this perceptual illusion can be shown with other substances than wine. From an experimental point of view, the use of this perceptual illusion has the advantage of its transparency to the subject. The task asked to be accomplished in the test presents no apparent “trap,” so that it induces no attempt of skirting which could modify the subject answer.

The perceptual illusion described here shows that, for the task considered, the sensory component is negligible compared to the cognitive component. According to the nonolfactory parameters, a given olfactory stimulus can induce the conscious perception of several different odors for a same subject, the perception of some odors excluding the others. The access to color, or lack thereof, leads to the cognitive construction of two distinct representations of the same object. The integration of color in this cognitive construction occurs in an unconscious way. The color exerts on smell a priming effect. The implicit form of memory implied does not apparently result from training. A preliminary experiment of wine tasting did not allow the subjects to connect the odor and the color of the wines. Indeed, wines do not specifically have the odors of objects with the same color as the wine.

The perceptual illusion concerns the names of the odors, and one may wonder whether the influence of color is related to the step of verbalization. Does the presence of a color induce the perception of the odor of an object with this color in the absence of words? When subjects are proposed to associate a color (or the name of a color) with an odor they smelled (but not necessarily identified), it appears that there exists a nonrandom odor–color association for a group of individuals (Gilbert et al., 1996). In their interpretation, the latter authors do not exclude the possibility of a relation between color lightness and odor intensity, as shown elsewhere by the same group (Kemp & Gilbert, 1997). However, it should be noted that the correspondence between odor and color evidenced in absence of verbalization and identification does not imply a semantic cause as is the case in our study. This result tends to prove that the phenomenon we observed is directly related to the identification of the odor, i.e., to its verbalization.

The fact that different odor–color associations are carried out in verbal (our work) and nonverbal tasks (Gilbert et al., 1996) is in agreement with the dual-coding theory (Paivio, 1986). Indeed, if it exists two mnemonic representations of the same information, there must necessarily be two equivalent perception representations. The fact that the odor–color associations from these two representations are stable is consistent with the existence of imaginal and verbal representations of odors and with the stability of these representations. However, it is not possible to prove the simultaneous existence of these two representations or their independence. One may consider that the verbal representation results from a higher processing of the imaginal representation which would be, in the event of a verbalization, an intermediary representation allowing a verbal representation to be constructed. The formalization carried out by the language would “erase” the imaginal representation. Indeed, the nonsemantic odor–color correspondence is replaced by a semantic one. The “tip-of-the-nose” phenomenon (Lawless & Engen, 1977) would then be a witness of the passage from one representation to the other, highlighting the sequential aspect of the appearance of the two representations.

We observed that the verbal representation of the odors does not result from a

specifically olfactory process. It appears that visual information was integrated into the process of verbalization itself. A modality specific coding of the representations is not compatible with the organization of the cerebral sensory projections. Physiological and, more recently, cerebral imaging data show that there are many convergences between the various cerebral pathways of sensory modalities. In mammals, simultaneous injections of different anterograde tracers in the retina and olfactory bulbs show convergent projections from the retina and from the olfactory bulbs in various parts of the primary olfactory cortex (Cooper et al., 1994). Recordings from single neuron activities of macaques show that the orbitofrontal cortex may act as a region of visual, gustatory, and olfactory convergence. Neurons in this region were found to respond to gustatory, olfactory, or visual stimulation (Rolls & Baylis, 1994).

More recently, PET scanning has shown that high-level odor processing induces the activation of area V1 of the primary visual cortex (Royet et al., 1999). This cortical area is involved in the early processing of visual information and is activated in identifying objects and generating mental visual images (Kosslyn et al., 1995). The authors suggest that the high-level odor processing requires a visual identification of the objects evoked by the odors. If such is the case, one could expect that the addition of visual information, such as color, could induce the formation of a mental visual image of an object with this color. Color would be integrated as an external component in the formation of the mental visual image, so that the identification of odor would result from the identification of this mental visual image. This interpretation allows to explain both the influence of color on the verbalization of olfactory information as well as the reduction in performance observed in the odor recognition when a subject has access to color.

In agreement with the results of Royet et al., a more recent PET study shows that the left cuneus (part of the primary visual cortex) is specifically activated during an olfactory naming task (Qureshy et al., 2000).

The hypothesis that the identification of an odor results from a visual identification of the mental representation of the object having this odor could be the reason why humans never developed specific olfactory terms to describe odors. Indeed, if odor identification results from a visual process, it is logical that the odor is identified using visual identifiers.

Our results tend to confirm that sense of smell is, by itself, unlikely to provide sufficient information to allow for a consciously reasoned decision. The capacity to identify odors could only be an accessory aspect of the olfactory function. The true function of smell is probably sought elsewhere.

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